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BULLETIN
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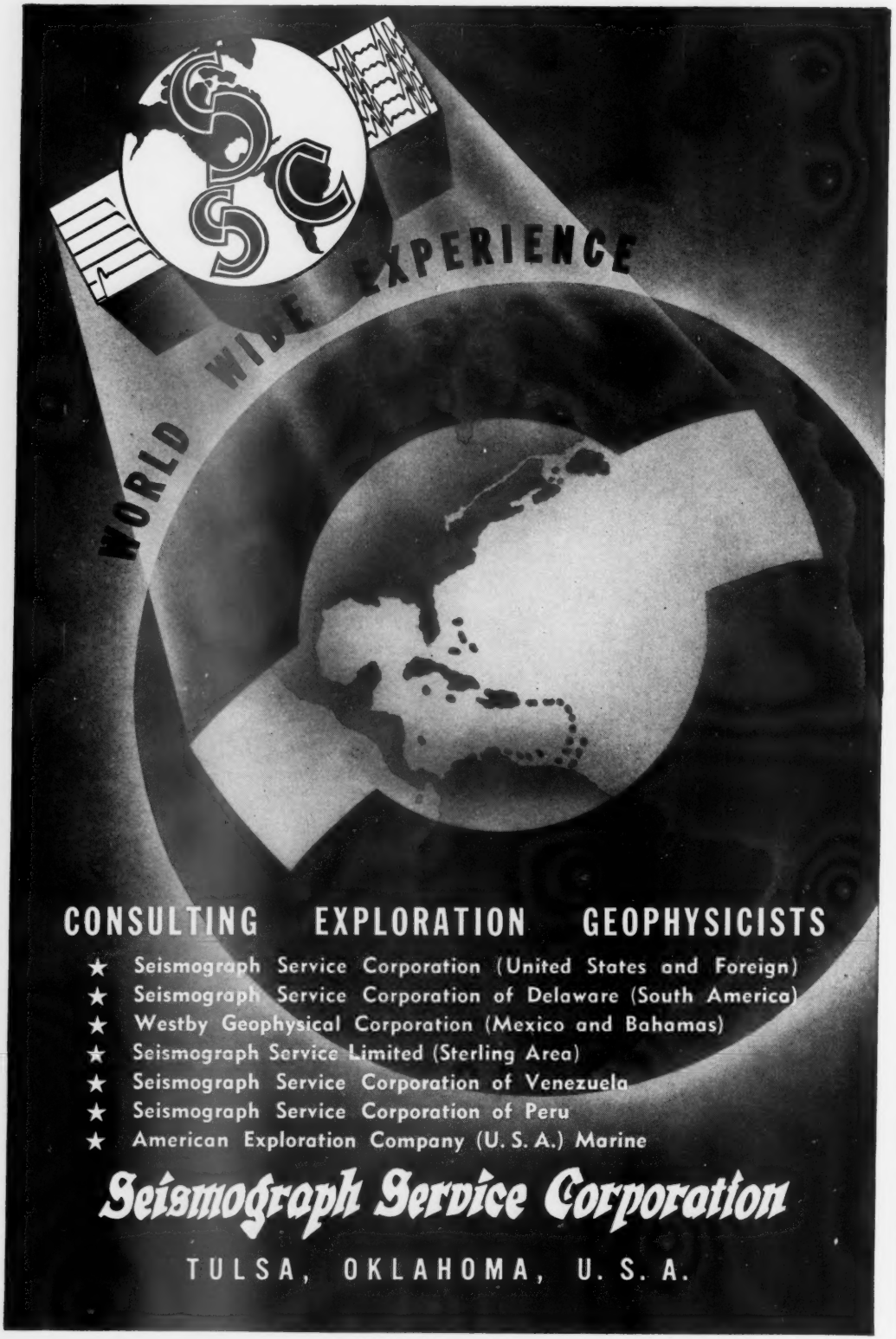
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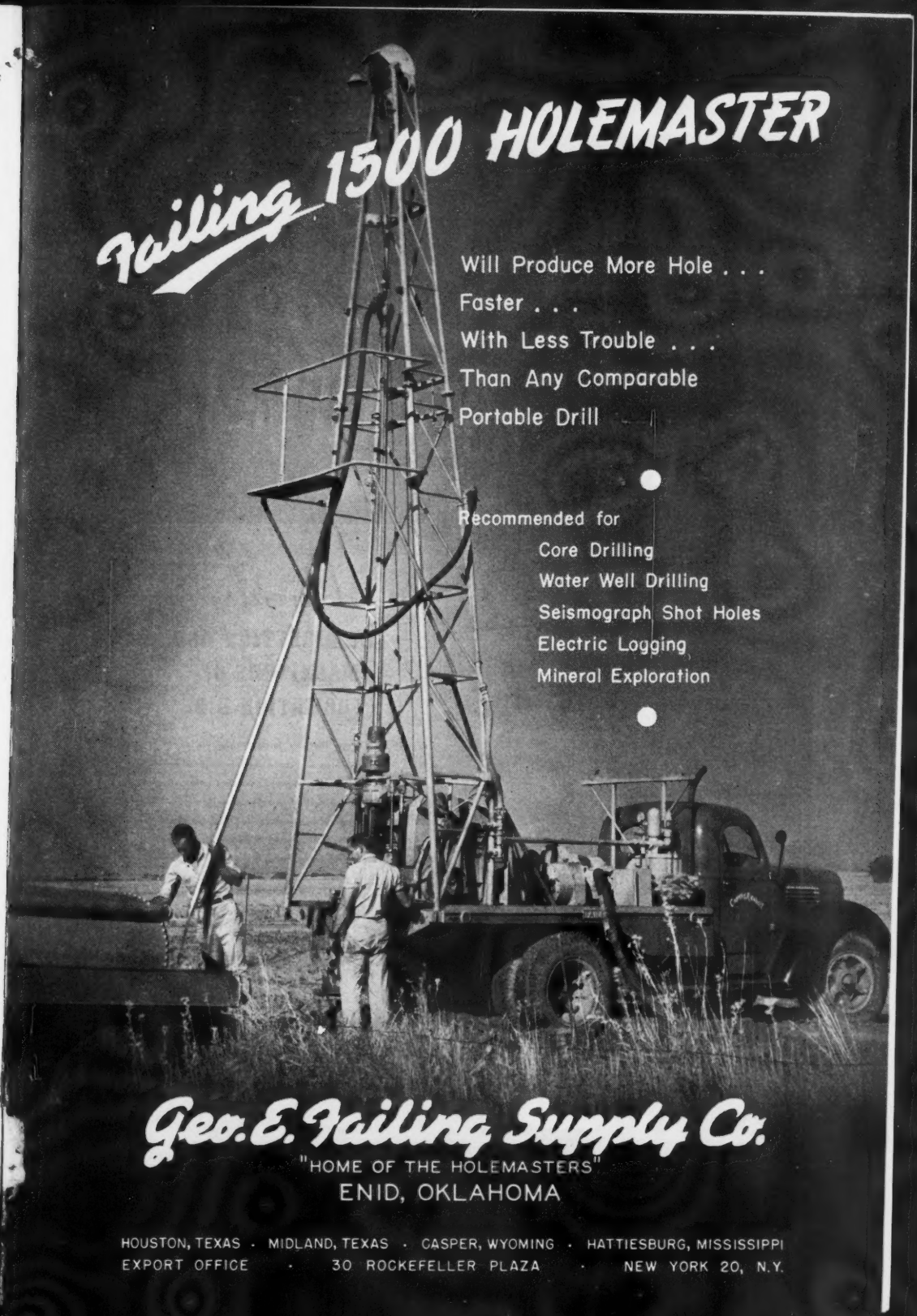
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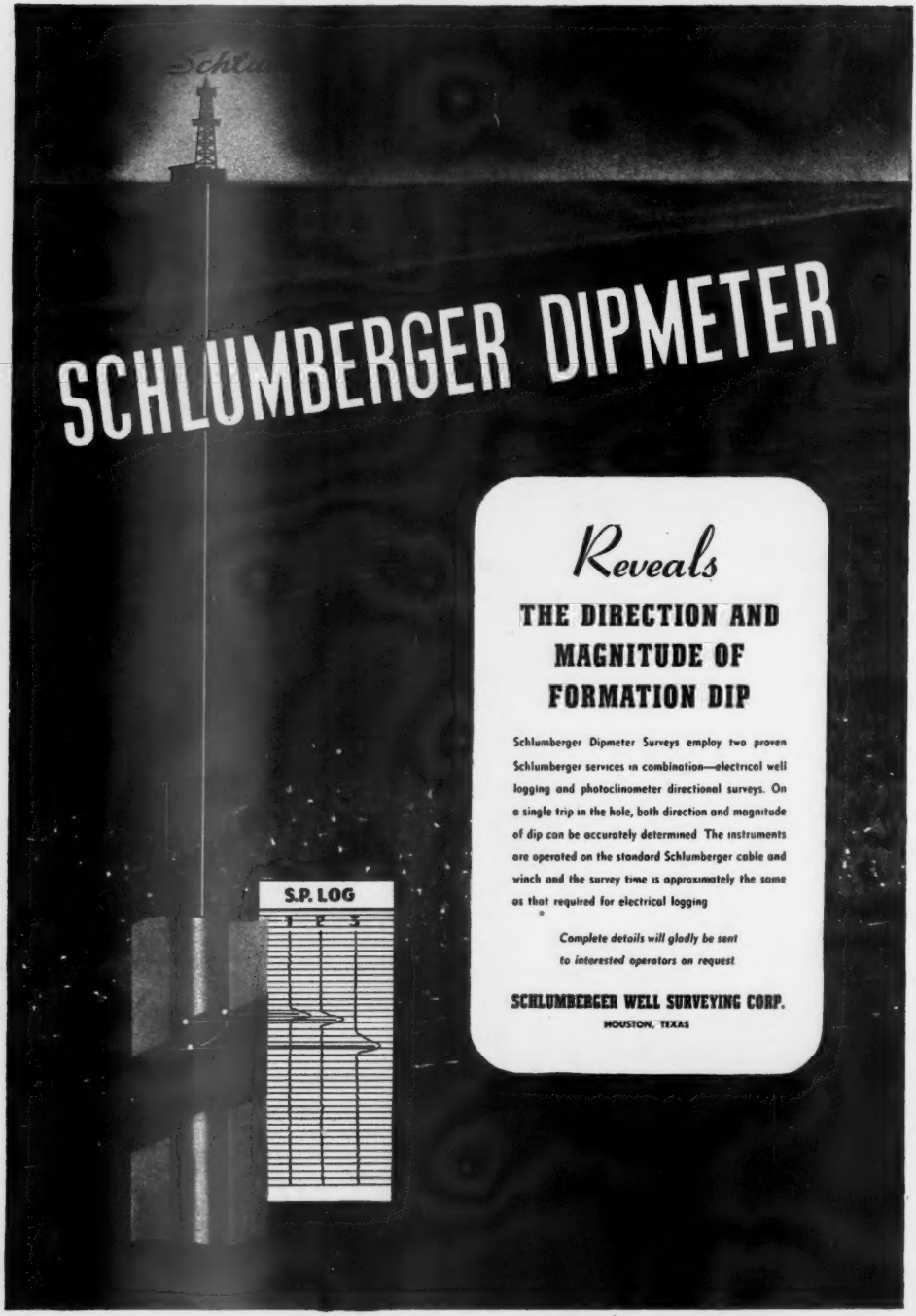
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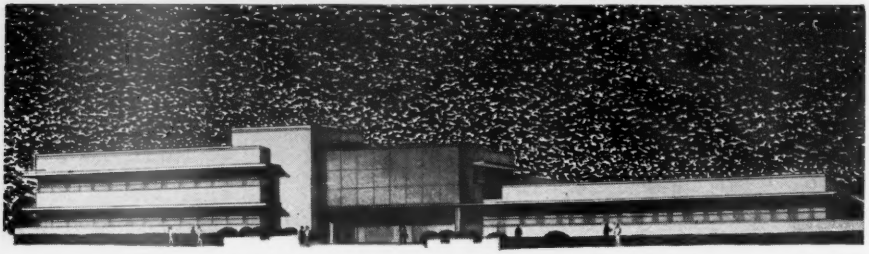

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APRIL, 1948

OIL FIELDS OF ROYAL DUTCH–SHELL GROUP IN WESTERN VENEZUELA[1]

STAFF OF CARIBBEAN PETROLEUM COMPANY[2]
Maracaibo, Venezuela

PART I. INTRODUCTION

GENERAL REMARKS

The Royal Dutch-Shell Group, through the Caribbean Petroleum Company and its associates, at present operates in western Venezuela eleven fields, which are located in the State of Zulia, in the Maracaibo Basin (Fig. 1). A list of these fields and relevant general data are given in Table I.

The first five fields in Table I are usually referred to as the Bolivar Coast fields on account of their location in the Bolivar District on the east shore of Lake Maracaibo.[3] Actually they are parts of one very large field in which accumulation

[1] Manuscript received, October 17, 1947. The paper was essentially written in January, 1946, and covers developments to the end of 1945.

[2] W. H. Bostock and D. B. Williams assembled the data on development, drilling methods, completion practice, reservoir conditions and production, and H. P. Schaub compiled the geological information and edited the manuscript. The writers are indebted to L. Kehrer, P. de Schumacher, A. N. Lucie-Smith, R. A. Henkes, J. T. Warde, A. J. Akehurst, A. J. Dikkers, J. J. Dozy, W. F. G. L. Starrenburg, and R. W. Barker of the Caribbean Petroleum Company for many helpful suggestions and for reading the manuscript.

The writers could spare only little time from their general duties and had to rely heavily on reports, maps, and sections already in the files of the Caribbean Petroleum Company. Among others private reports by the following members of the technical staff of the Caribbean Petroleum Company have been used.

Regional geology: P. Bitterli, H. Buess, W. Hegwein, L. Kehrer, J. Krebs, E. Kündig, E. A. Ritter, H. P. Schaub, H. Stauffer, W. Tappolet, W. G. C. Tomalin.

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Oil and water analyses: L. A. Britton, G. M. Minnema.

[3] Lake Maracaibo is a translation of the Spanish name Lago de Maracaibo. This large body of brackish water, which is connected with the open sea through a wide channel with several shallow openings, is a nearly closed bay rather than a true lake.

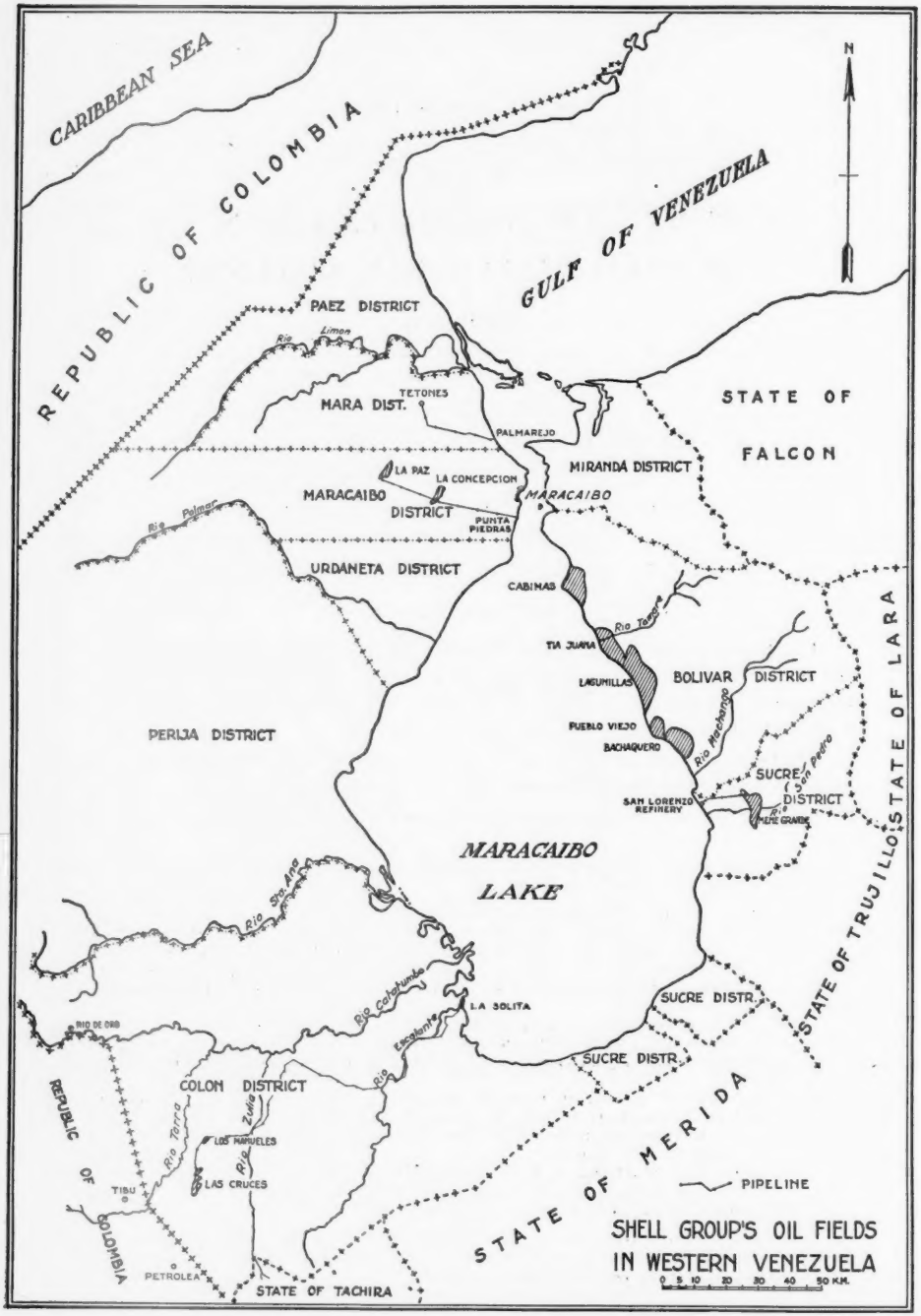


FIG. 1.—Map of State of Zulia showing political subdivision and Shell Group's oil fields.

took place under similar stratigraphical and structural conditions and consequently they are treated as a group.

Las Cruces and Los Manueles fields exploit separate accumulations on the Tarra anticline. In both, oil occurs in the same formations under similar structural conditions, and these fields are therefore presented in one comprehensive description.

TABLE I

LIST OF SHELL GROUP'S OIL FIELDS IN WESTERN VENEZUELA

Field	*Concessionaire*	*District*	*Main Production from*	*Potential Production Dec., 1945, Bbls.*
Cabimas	Venezuelan Oil Concessions Ltd.	Bolivar	Miocene	17,850
Tia Juana	Venezuelan Oil Concessions Ltd.	Bolivar	Miocene	35,600
Lagunillas	Venezuelan Oil Concessions Ltd.	Bolivar	Miocene	72,000
Pueblo Viejo	Venezuelan Oil Concessions Ltd.	Bolivar	Eocene	3,550
Bachaquero	Venezuelan Oil Concessions Ltd.	Bolivar	Miocene	32,250
Mene Grande	Caribbean Petroleum Company	Sucre	Miocene Eocene	35,850
Concepción	Venezuelan Oil Concessions Ltd.	Maracaibo	Eocene	3,400
La Paz	Venezuelan Oil Concessions Ltd.	Maracaibo	Eocene Cretaceous	27,000
Tetones	Caribbean Petroleum Company	Mara	Cretaceous	6,150
Las Cruces	Colón Development Company Ltd.	Colón	Eocene	12,300
Los Manueles	Colón Development Company Ltd.	Colón	Eocene	4,800

OUTLINE OF GEOLOGICAL HISTORY OF MARACAIBO BASIN

(Fig. 2)

The geological history of the Maracaibo Basin is intricate and only partly known. Over large areas of the basin which are covered by the Maracaibo Lake and by the piedmont plains descending from the surrounding mountain ranges, only geophysical information is available. Even in some of the oil fields only a very small part of the sedimentary cover has been explored as yet and, in order to arrive at conclusions about conditions in the interior of the basin, the geologist has to rely on studies of the formations and structures exposed in the surrounding highlands.

Geologically, the formation of the Maracaibo Basin, as we know it to-day, was quite recent. As far as can be judged at present, geological history was nearly identical over all of western Venezuela during Paleozoic and Mesozoic time. In the Eocene marked differences in facies developed in different areas, and it is only from the Miocene onward that we can discern the existence of the Maracaibo Basin as such.

A thick series of sediments was formed during the Paleozoic era. Ordovician,

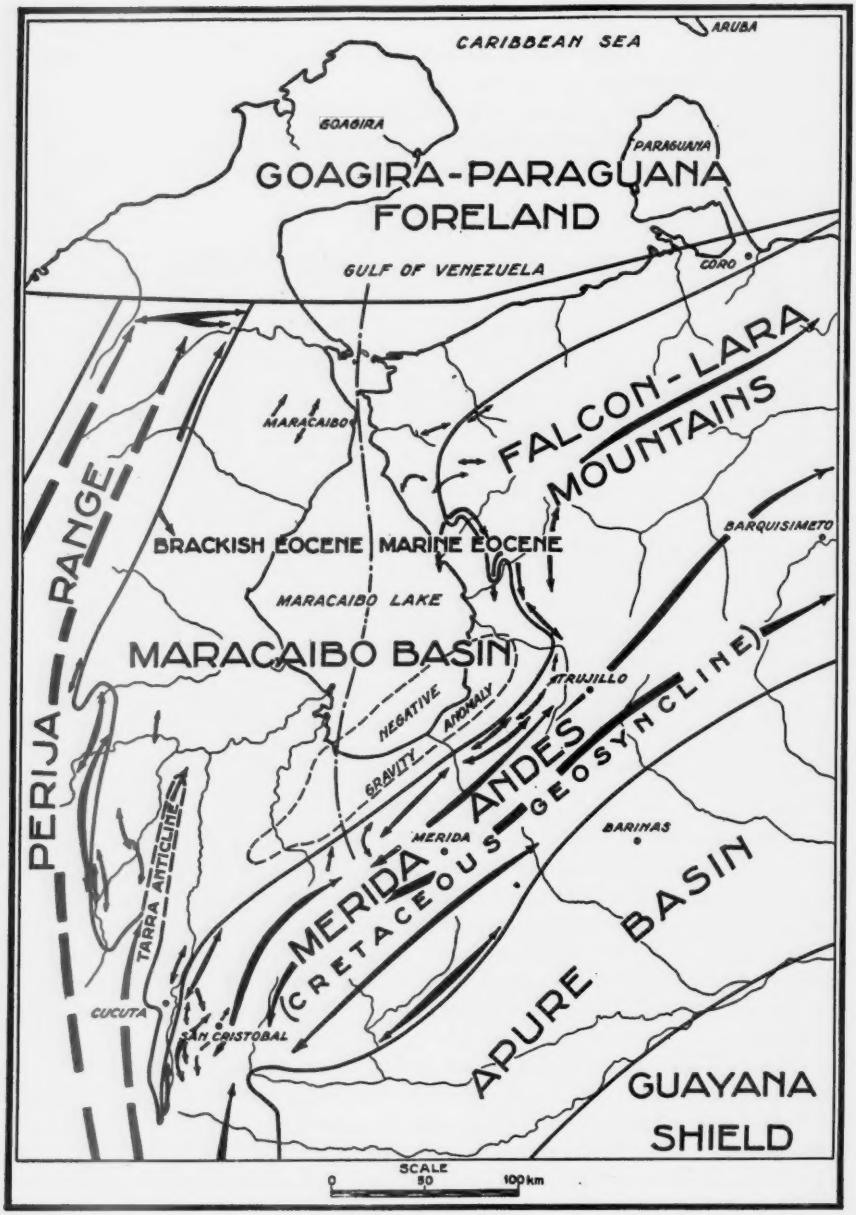
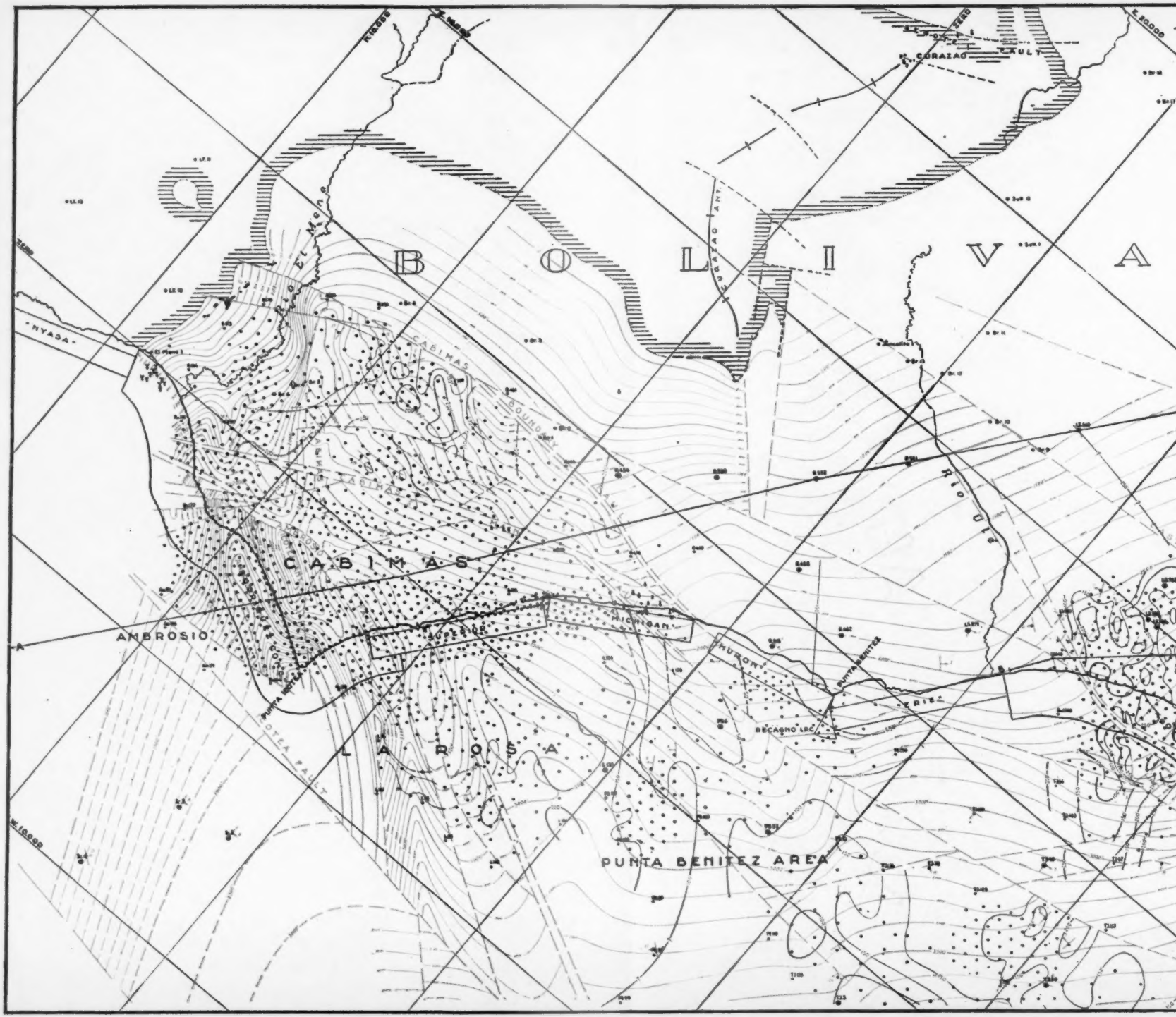
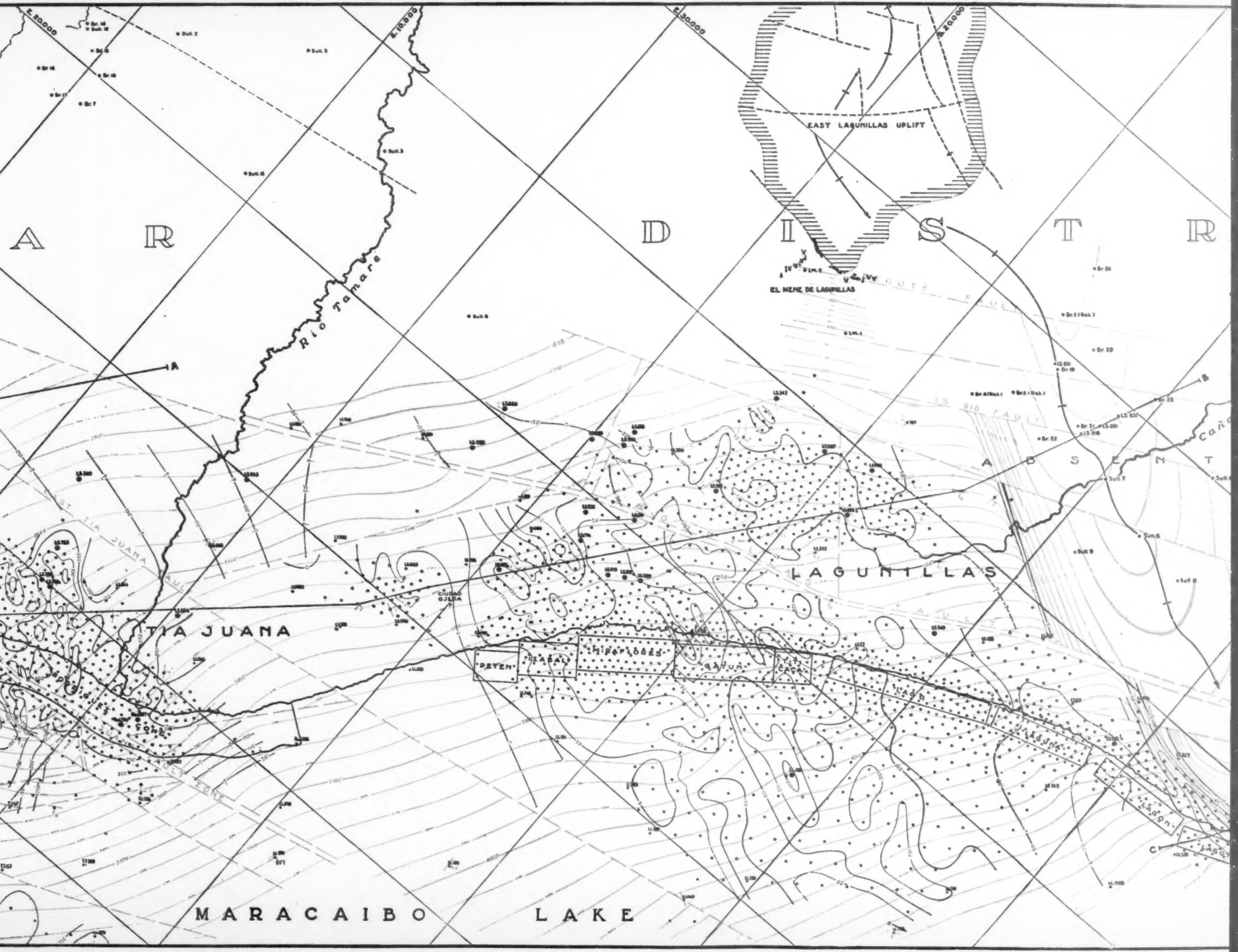
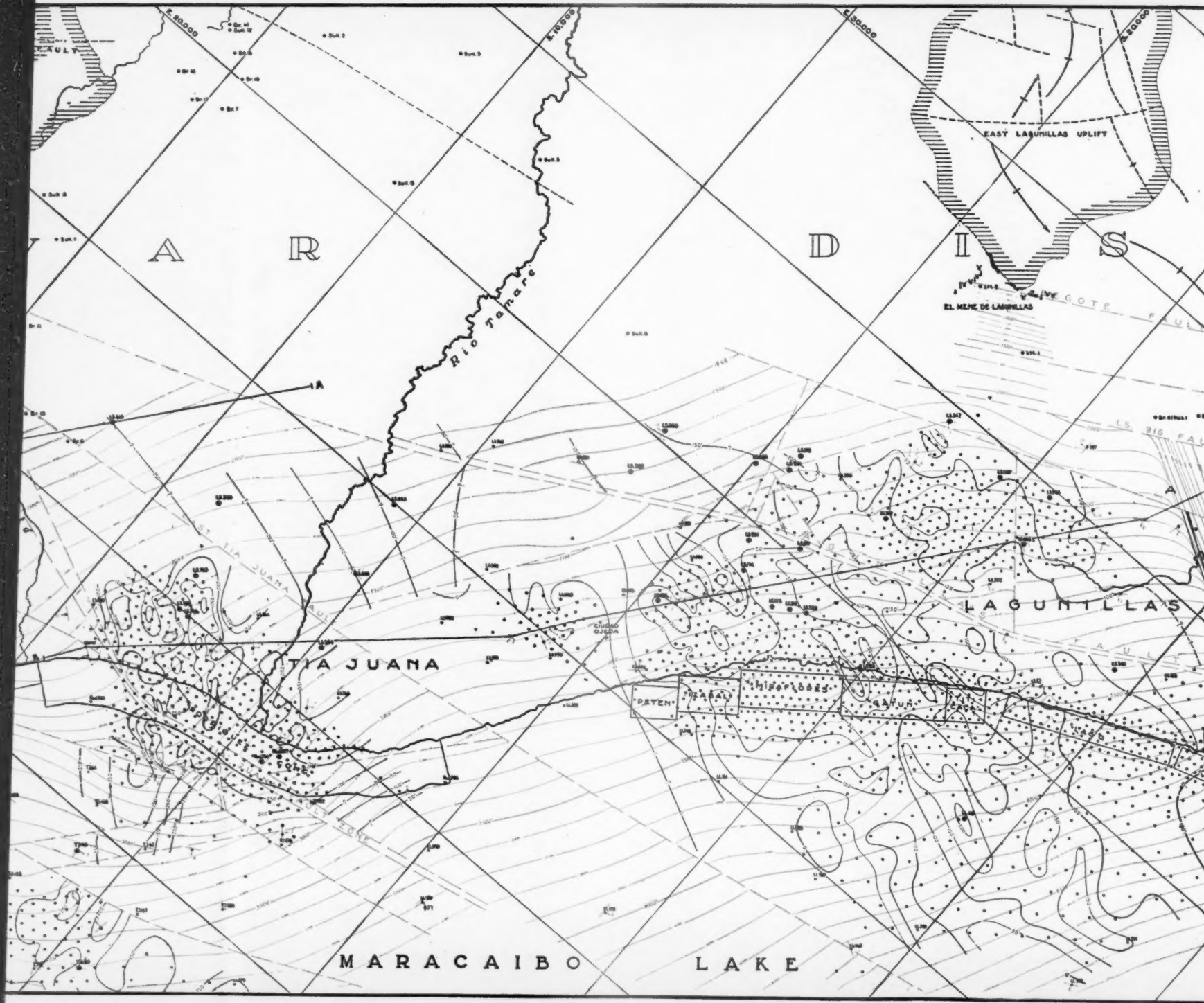


FIG. 2.—Map showing geotectonic units of western Venezuela and approximate extent of marine and brackish facies in Eocene of Maracaibo Basin.


BOLIVA
CABIMAS
LA ROSA
AMBROSIO
PUNTA BENITEZ AREA
MICHIGAN
HURON
PUNTA BENITEZ
BECAGNO LRC
CORAZAO
CABIMAS BOUNDARY FAULT
LA ROSA FAULT
PUNTA NOTLA
NYASA
RIO EL MOJAN
RIO UIRE


EAST LAGUNILLAS UPLIFT
EL MENE DE LAGUNILLAS
Río Tamare
A
B
A R
D I S T R
A B S E N T
LAGUNILLAS
TIA JUANA
MARACAIBO LAKE
Ciudad Ojeda


A R
D I S
EAST LAGUNILLAS UPLIFT
EL MENE DE LAGUNILLAS
Río Tamare
TIA JUANA
LAGUNILLAS
MARACAIBO
LAKE

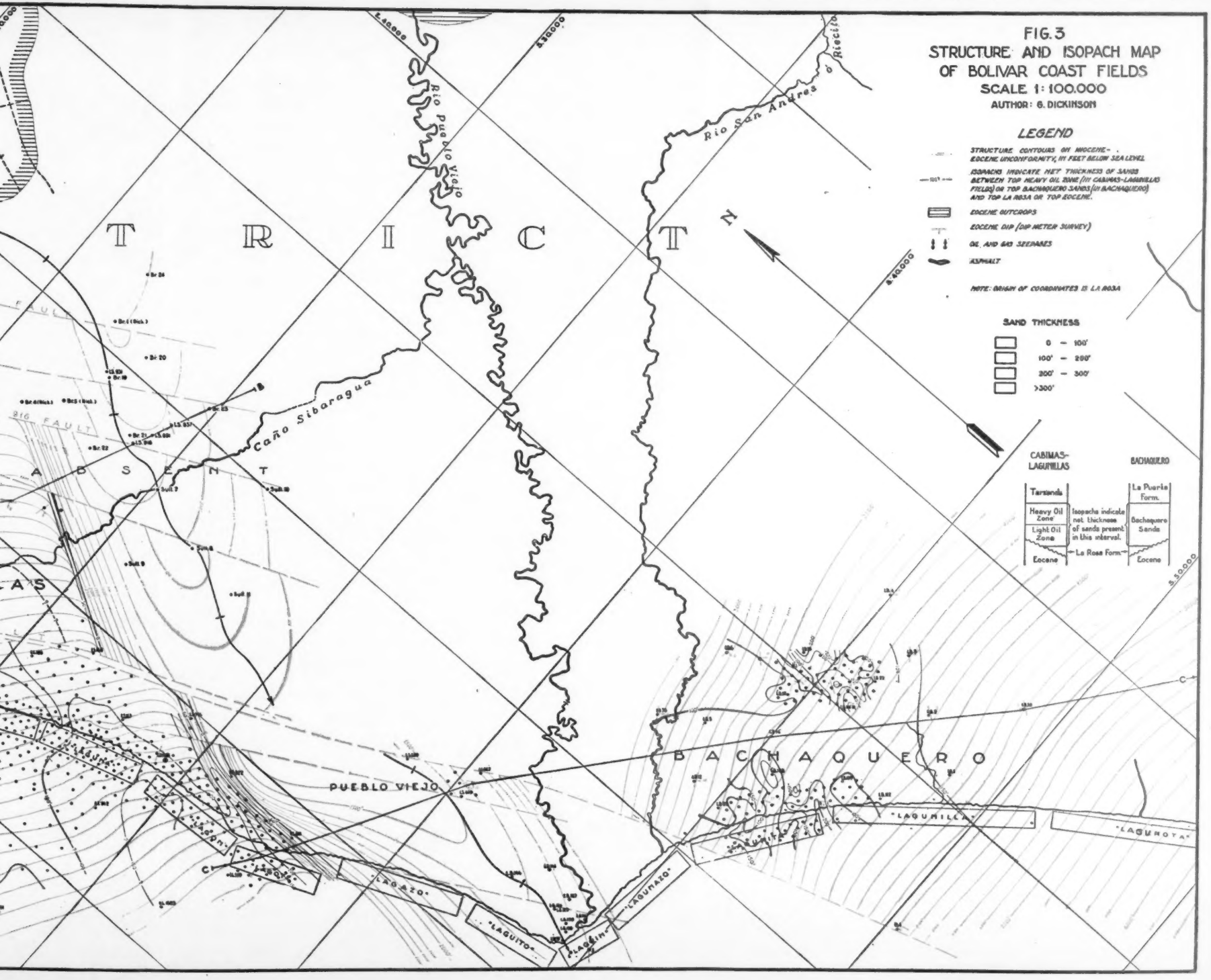
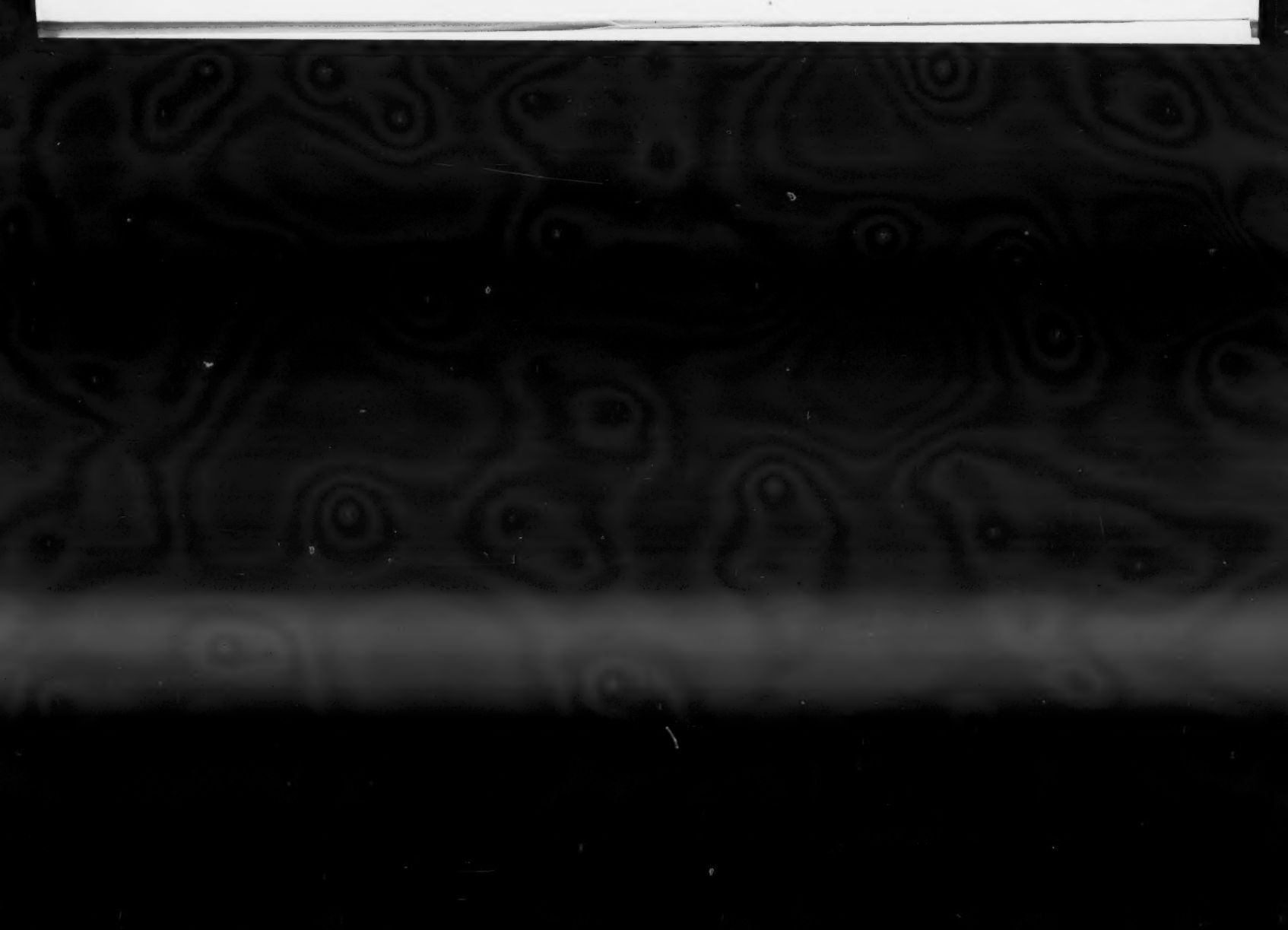


FIG. 3
STRUCTURE AND ISOPACH MAP
OF BOLIVAR COAST FIELDS
SCALE 1: 100.000
AUTHOR: G. DICKINSON
LEGEND
STRUCTURE CONTOURS ON MIOCENE-EOCENE UNCONFORMITY, IN FEET BELOW SEA LEVEL
ISOPACHS INDICATE NET THICKNESS OF SANDS BETWEEN TOP HEAVY OIL ZONE (IN CABIMAS-LAGUNILLAS FIELDS) OR TOP BACHAQUERO SANDS (IN BACHAQUERO) AND TOP LA ROSA OR TOP EOCENE.
EOCENE OUTCROPS
EOCENE DIP (DIP METER SURVEY)
OIL AND GAS SEEPAGES
ASPHALT
NOTE: ORIGIN OF COORDINATES IS LA ROSA
SAND THICKNESS
0 – 100'
100' – 200'
200' – 300'
>300'
CABIMAS-LAGUNILLAS
BACHAQUERO
Tertiary
Heavy Oil Zone
Light Oil Zone
Eocene
Isopachs indicate net thickness of sands present in this interval.
La Rosa Form.
La Puerta Form.
Bachaquero Sands
Eocene
TRICT
ABSENT
Río Pueblo Viejo
Río San Andres o Riecito
Caño Sibaragua
FAULT
PUEBLO VIEJO
BACHAQUERO
"LAGUNILLA"
"LAGUNOTA"
"LAGAZO"
"LAGUITO"
"LAGUNAZO"
"LAGUNETA"
"LAGUNETA"
"LAGUNETA



Devonian, and Permo-Carboniferous faunas have been reported from various localities in the Mérida Andes and the Perijá Range,[4] where formations belonging to these systems are conserved in a non-metamorphic state. The greater part of the Paleozoic formations were, however, subjected to regional metamorphism during strong orogenic movements probably belonging to the Hercynian phase, which were accompanied by the intrusion of large igneous masses.

The mountain ranges resulting from this orogeny were again levelled and part of the débris was deposited as the La Quinta formation which transgresses over the older formations. It is mainly composed of redbeds (conglomerates, sandstones, and sandy shales), probably Triassic to Jurassic in age.

New tectonic movements set in after the deposition of the La Quinta formation. It is interesting to note that the main remnants of this formation are found to-day along a belt in the interior of the Mérida Andes, while it is missing in the northern and southern foothills in Petrólea, Tibú, La Paz, and Tetones (Fig. 1), where the Cretaceous transgresses onto metamorphic and igneous rocks. There is thus reason to believe that it is also missing over most of the Maracaibo Basin. It is not quite clear whether the La Quinta formation was deposited only in a trough which could be called the Triassic-Jurassic forerunner of the Andean geosyncline, or whether it was removed by erosion in areas of positive epeirogenic tendencies during early Cretaceous time, that is, in the early stages of the geosyncline. The La Quinta formation is probably also present in the interior of the Perijá Range.

The Cretaceous begins with a transgression throughout western Venezuela. In the deeper parts of the Andean geosyncline it commences with the Lower Cretaceous, which lies unconformably on the La Quinta formation, but it has not been determined with certainty whether the earlier stages (Valanginian and Hauterivian) were deposited in western Venezuela. The lowermost Cretaceous formation (Tomón or Uribante), which is composed mainly of sandstone and some limestones, shows a distinct thinning from the geosyncline northward and is absent in the La Paz field, where the Cogollo formation of Aptian-Albian age transgresses onto the basement. It is thus apparent that the area of the Maracaibo Basin remained uplifted and stable during the early Cretaceous in contrast to the Andean geosyncline where the Tomón formation reaches great thickness.

During the Middle and Upper Cretaceous, sedimentation took place in an open, probably shallow sea. The formations are generally developed best in the Andean geosyncline where the facies is predominantly shaly. A calcareous facies has been observed in the northern half of the Maracaibo Basin, mainly in the Cogollo formation.

[4] P. Christ, "Coupe géologique le long du chemin de Mucuchachí a Sta. Bárbara dans les Andes vénézuéliennes," *Eclogae Geol. Helv.*, Vol. XX, No. 3 (1927).

R. A. Liddle, *Geology of Venezuela and Trinidad*, pp. 97–101. Fort Worth (1928).

L. Kehrer, "Some Observations on Cretaceous and Pre-Cretaceous Beds in the Southwestern and Northern Central Parts of Venezuela," *Bol. Geología y Mineria*, Tómo I, Nos. 2–4. Caracas (1938).

R. A. Liddle, G. D. Harris, and J. W. Wells, "The Rio Cachirí Section in the Sierra de Perijá, Venezuela," *Bull. Amer. Palaeon.*, Vol. 27, No. 108 (1943).

H. P. Schaub, "Fusulinids in La Quinta Formation, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 11 (November, 1944).

A thin glauconite bed, which rests conformably on the La Luna formation and marks the base of the Colón formation, can be recognized in most Cretaceous sections. It probably indicates reduced sedimentation over an extended period and a change of environment, but this was not accompanied by emergence and no unconformity resulted.

Facies distribution in the Tertiary does not seem to be greatly influenced by the Andean geosyncline, but rather by a geosynclinal trough in the region of the Falcón-Lara Mountains. In the western parts of the Maracaibo Basin a predominantly brackish facies with many coal seams is found throughout the Tertiary section, while marine beds such as orbitoidal limestones and shales commonly occur in the eastern half. The Eocene is much thicker in the marine than in the brackish facies.

There are other important differences between the two areas. Sedimentation was uninterrupted in large parts[5] of the western half of the Maracaibo Basin from the Middle Cretaceous to the late Miocene, when the Andean orogeny took place. In the eastern half, on the contrary, several unconformities are known within the Tertiary section, and it is possible that the Eocene rests unconformably on the Cretaceous in certain areas, although this still remains to be proved. Of particular importance for the present study is the unconformity which separates Eocene and Miocene in the Bolivar District.

Tectonic movements started in late Eocene time (early Jacksonian) and were probably strongest during late Oligocene. Anticlines and synclines were formed, large-scale faulting occurred, and intensive erosion followed in the northern and eastern parts of the basin, in some places even denuding the basement. The resulting landscape was gradually submerged under the transgressing Miocene sea. During these pre-Andean movements the eastern, southeastern and possibly the northwestern rims of the Maracaibo Basin slowly took shape, while the southwestern half remained undisturbed.

The Andean orogeny probably began at the end of the Miocene and continued during the Pliocene, and only then were the Mérida Andes and the Perijá Range formed in their final shape, and the Maracaibo Basin closed in the south and west. The deepest part of the Maracaibo Basin remained relatively undisturbed during the whole orogenic cycle, except for pronounced subsidence, and was involved only slightly in the folding. Possibly sedimentation was never long interrupted in the center of the basin. It still continues to-day in Lake Maracaibo and in the swamps and lowlands at its southeastern end, under brackish conditions and possibly continuing subsidence.

As a result of the development described a very thick cover of sediments has accumulated in the Maracaibo Basin. For comparison the thicknesses calculated

[5] This is the case throughout the Colón District and neighboring areas of Táchira and Colombia, and also in the western Mara District. In the Perijá District, however, the Eocene is known to transgress on the Cretaceous.

in various parts of the basin have been compiled in Table II (Fig. 1 shows location).

STRUCTURAL OUTLINE

(Fig. 2)

The present shape of the Maracaibo Basin is mainly the result of the Andean orogeny. Structural elements of former orogenic phases were involved in the Andean movements and may have pre-determined many structural trends which seem to be contrary to the general direction of the Andean movements.

Mountain systems of Andean age border the Maracaibo Basin on three sides. On the west is the Perijá Range, which is the northern continuation of the Cordillera Oriental of Colombia. On the south rise the high peaks of the Mérida Andes. This range is separated from the Cordillera Oriental-Perijá Range by a cross-depression in the region south and west of San Cristobal (Táchira depression), which though still mountainous, is filled mainly with Tertiary sediments. The eastern rim of the basin is formed by the various mountain ranges of the states of Falcón, Lara, and eastern Zulia.

On the north the basin is bordered by a foreland, which was not involved in the Andean folding and is to-day represented by the Goajira and Paraguaná peninsulas and by the islands of Aruba, Curaçao, and Bonaire.

TABLE II

THICKNESS OF SEDIMENTARY COVER IN VARIOUS PARTS OF MARACAIBO BASIN (IN FEET)

Formation	*Colón District*	*Western Mara District*	*Bolivar District*
Miocene	10,000 or more	6,100 or more	8,000 or more
Eocene	16,200[1]	7,600[2]	17,000 minimum
Cretaceous	5,000	4,900	5,000[3]
Total	20,200 or more	17,600 or more	30,000 or more

[1] Includes Oligocene.
[2] May include Oligocene beds.
[3] As Cretaceous is unknown in Bolivar District thickness measured in State of Trujillo was used.

The strongest orogenic movements took place in the Mérida Andes. They resulted in the formation of a high mountain range with a metamorphic-igneous core, which is about 90 kilometers (67 miles) wide and extends 400 km. (240 miles) from San Cristobal in a northeasterly direction. Strong thrusts can be observed along its northern foot. Toward the north follows a very deep synclinal trough known from gravimetrical surveys, which forms the deepest part of the Maracaibo Basin. It is compensated by a positive anomaly of comparable size in the interior of the mountains. This and the northeasterly, or Andean, trend of the trough, indicate the intimate relation of origin between the deepest part of the Maracaibo Basin and the Mérida Andes.

The Perijá Range has a north-northwesterly trend in Colombia, but turns north-northeasterly north of Rio de Oro. Like the Mérida Andes it has an igneous-metamorphic core but the uplift was not as pronounced. A well defined east-west trend at the northern end of the Perijá Range indicates that the Andean orogeny met with strong resistance in this area, which has to be sought in the Goajira-Paraguaná foreland.

In the Táchira depression, separating the Mérida Andes and the Perijá Range, the structural trends of these two mountain systems (northeast and north to north-northwest) compete. Great shear faults are evidence of the strong stresses accompanying the orogeny in this area. The anticlines of the depression plunge north and northeastward and disappear, in part steeply, into the Maracaibo Basin. Some folds of the Cordillera Oriental also plunge into the basin, and, of these, the Tarra anticline is the most outstanding (see Part V).

Along the eastern rim of the Maracaibo Basin, north- and even northwest-striking structures are found although the general trend of the folds in the states of Lara and Falcón is northeasterly or Andean. In this area all anticlines turn sharply south out of a northeast-southwest trend and disappear with a strong southerly plunge into the basin.

Very little is known of the tectonics inside the basin, but as a rule the structures follow the trend of the nearest segment of the surrounding Andean system. La Paz and Concepción in the Maracaibo District may be mentioned as instances. In general the Maracaibo basin deepens gradually from north to south and widens from 140 km. (86 miles) in the north to a maximum width of 250 km. (153 miles) in the middle. Farther southwest it narrows gradually and disappears in the region south of Cúcuta.

The origin of the Maracaibo Basin, and particularly the reason for this area being so little involved in the Andean orogeny, are matters for much speculation.[6]

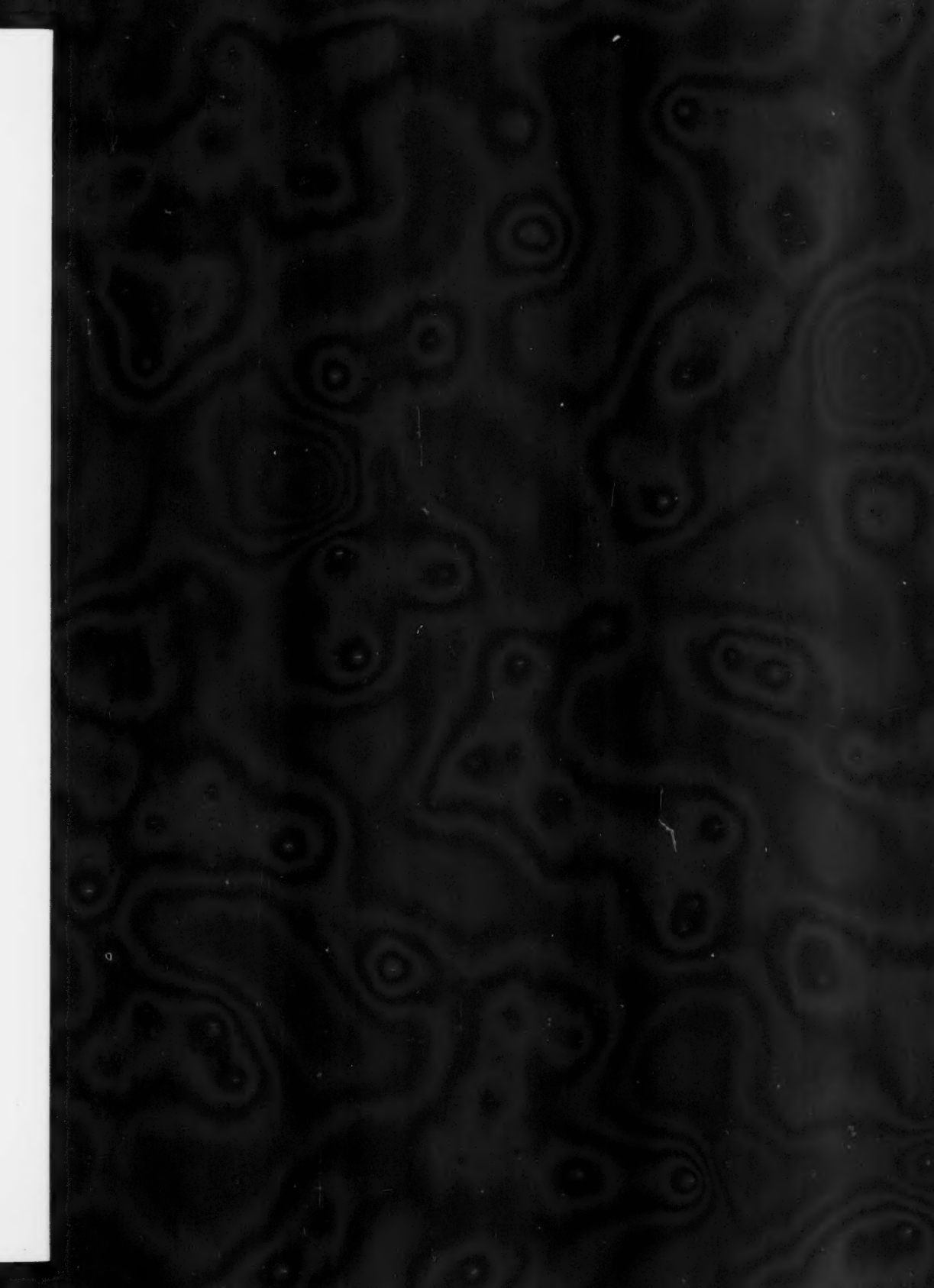
Part II. Bolivar Coast Fields

(Figs. 3–6)

INTRODUCTION

The Bolivar Coast fields of the Venezuelan Oil Concessions Limited stretch along the eastern shore of Lake Maracaibo nearly 70 km. (43 miles). From the northern end of the Cabimas field a continuous reservoir of Miocene sands extends to the southern end of the Lagunillas field, somewhat more than 50 km. (30 miles). Here it is interrupted by the Eocene uplift of Pueblo Viejo but may well be continuous under the lake, and corresponding formations are also oil-bearing in the Bachaquero field. Furthermore, the reservoir reaches into the area covered by Lake Maracaibo, where it is exploited by the Mene Grande Oil

[6] R. A. Liddle, "Tectonics of the Maracaibo Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 2 (1927). H. de Cizancourt, "Tectonic Structure of Northern Andes in Colombia and Venezuela," *ibid.*, Vol. 17, No. 3 (March, 1933).



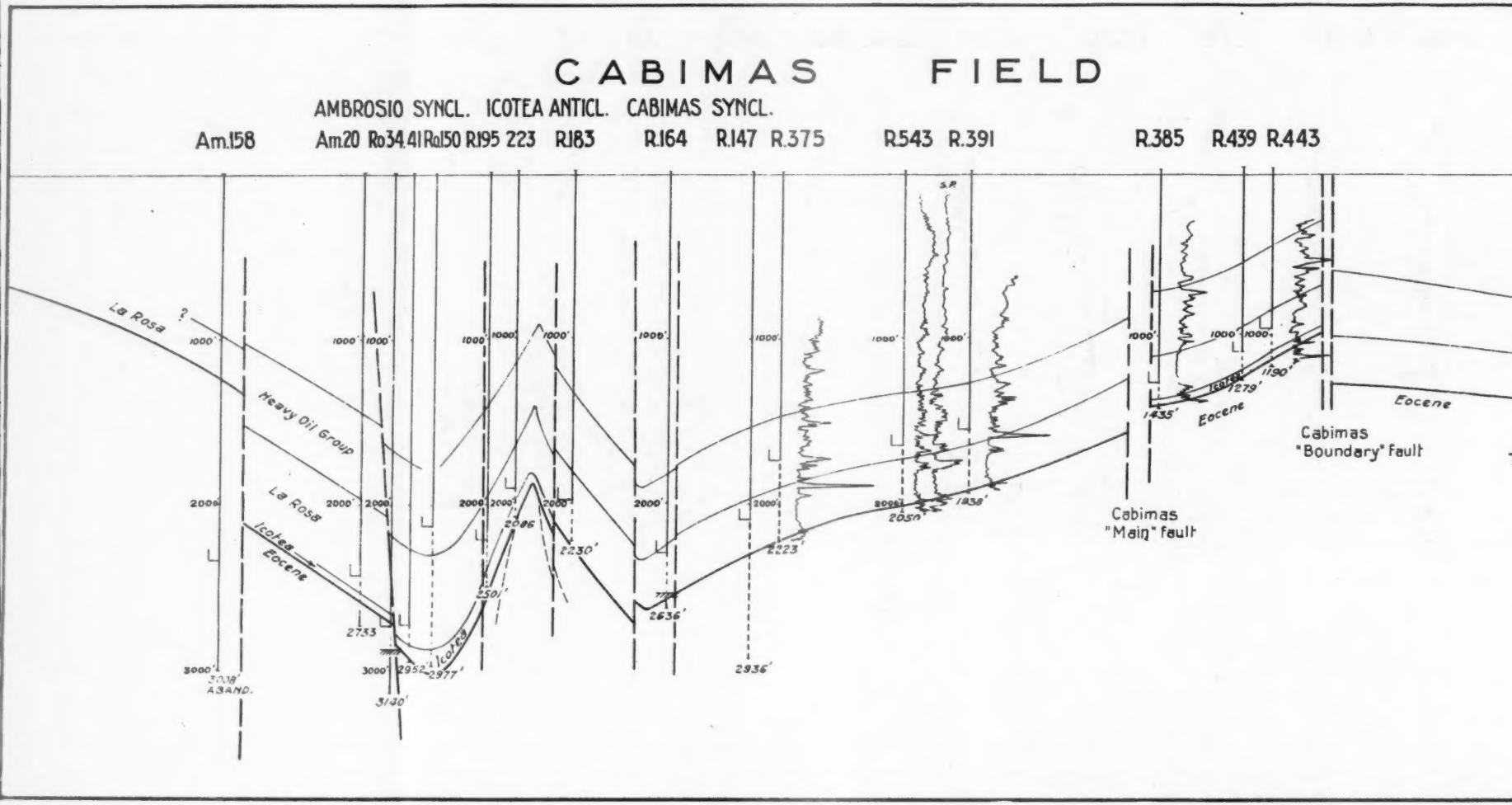
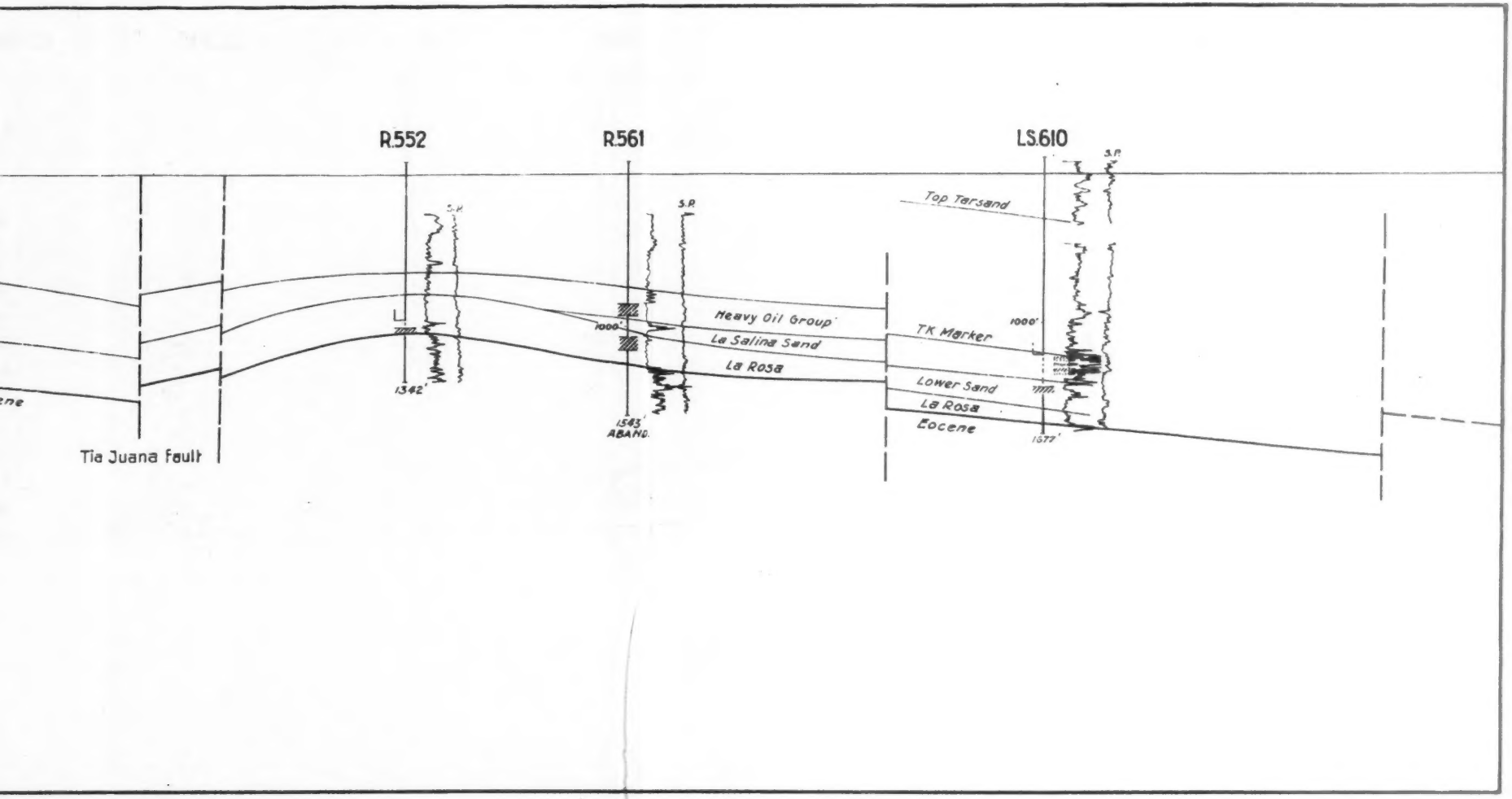


FIG. 4.—Section A through Bolivar Coast fields (Cabimas field), by G



s field), by G. Dickinson. Scale: horizontal, 1:50,000; vertical, 1:10,000.

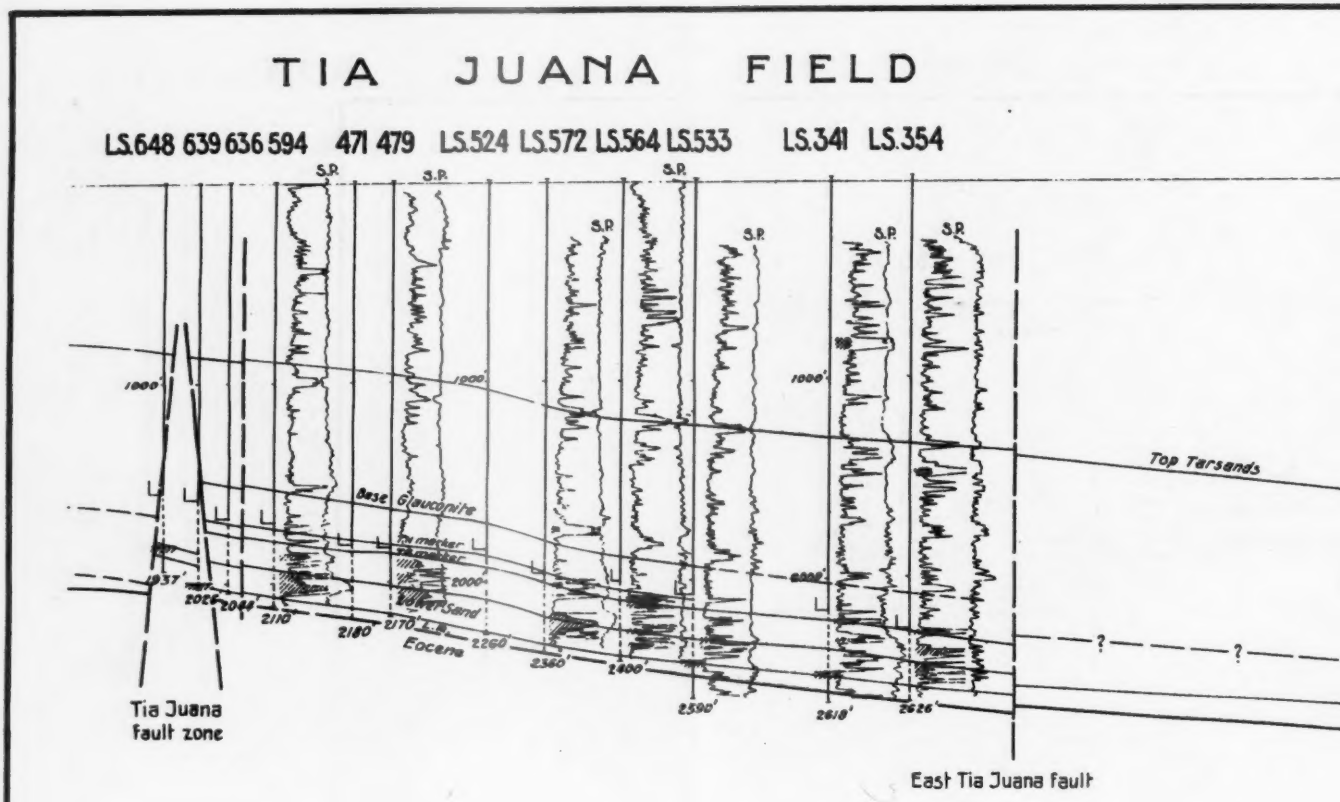
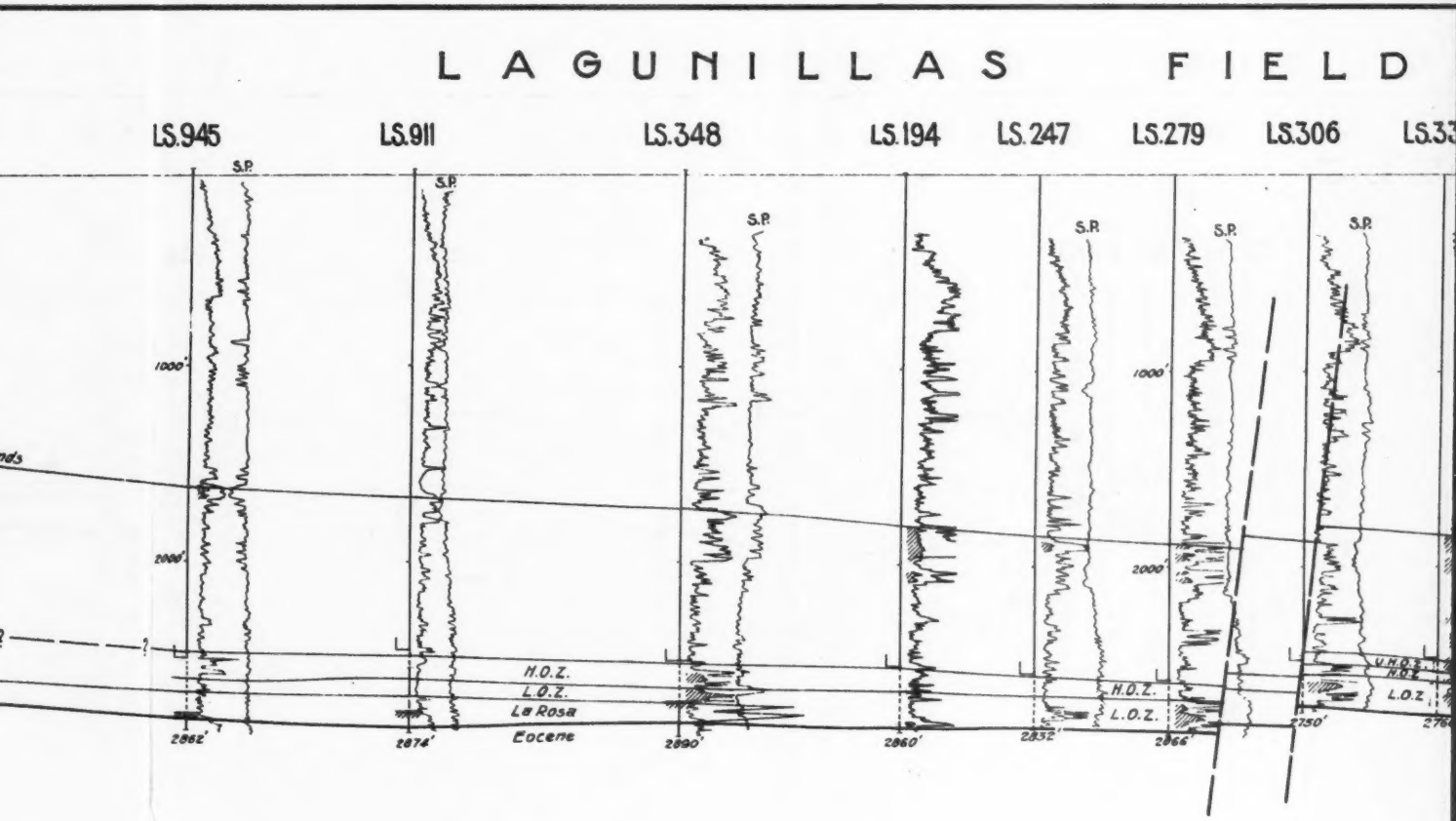


FIG. 5.—Section



5.—Section B through Bolivar Coast fields (Tia Juana to Pueblo Viejo), by G. Dickinson. Scale: horizontal, 1:50,000; vertical, 1:10,000. (U) H.O.Z.: (Upper) Heavy Oil zone. L.O.Z.:

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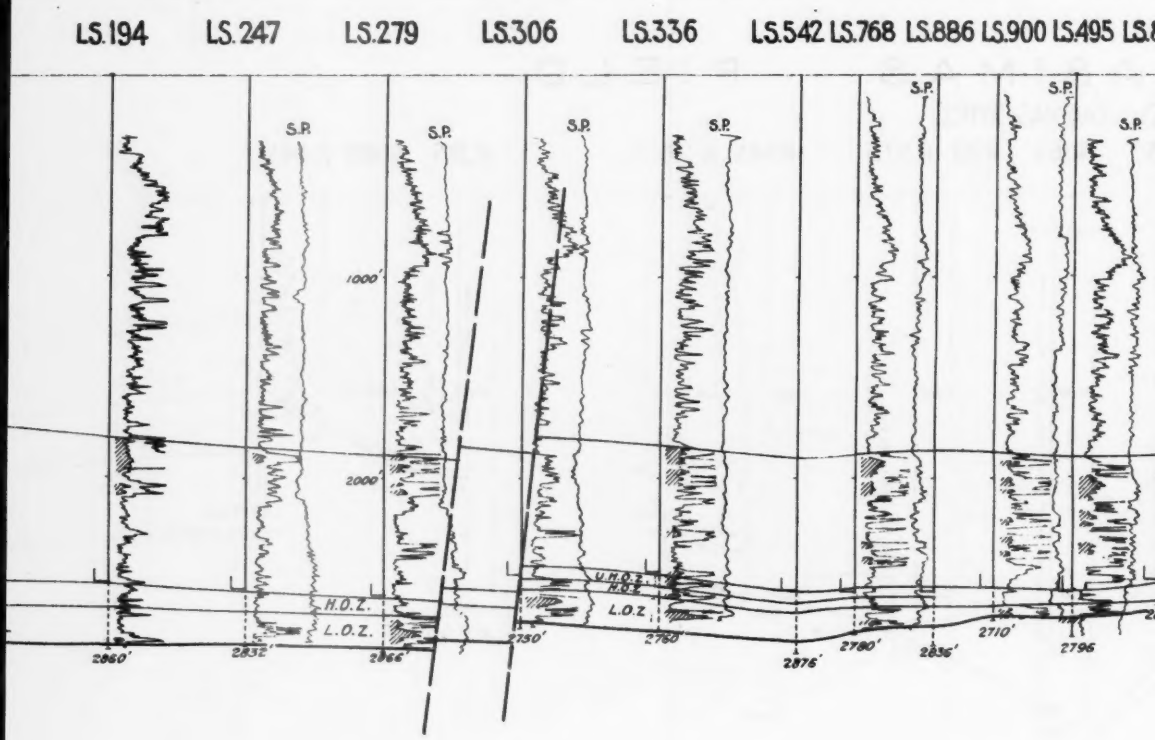
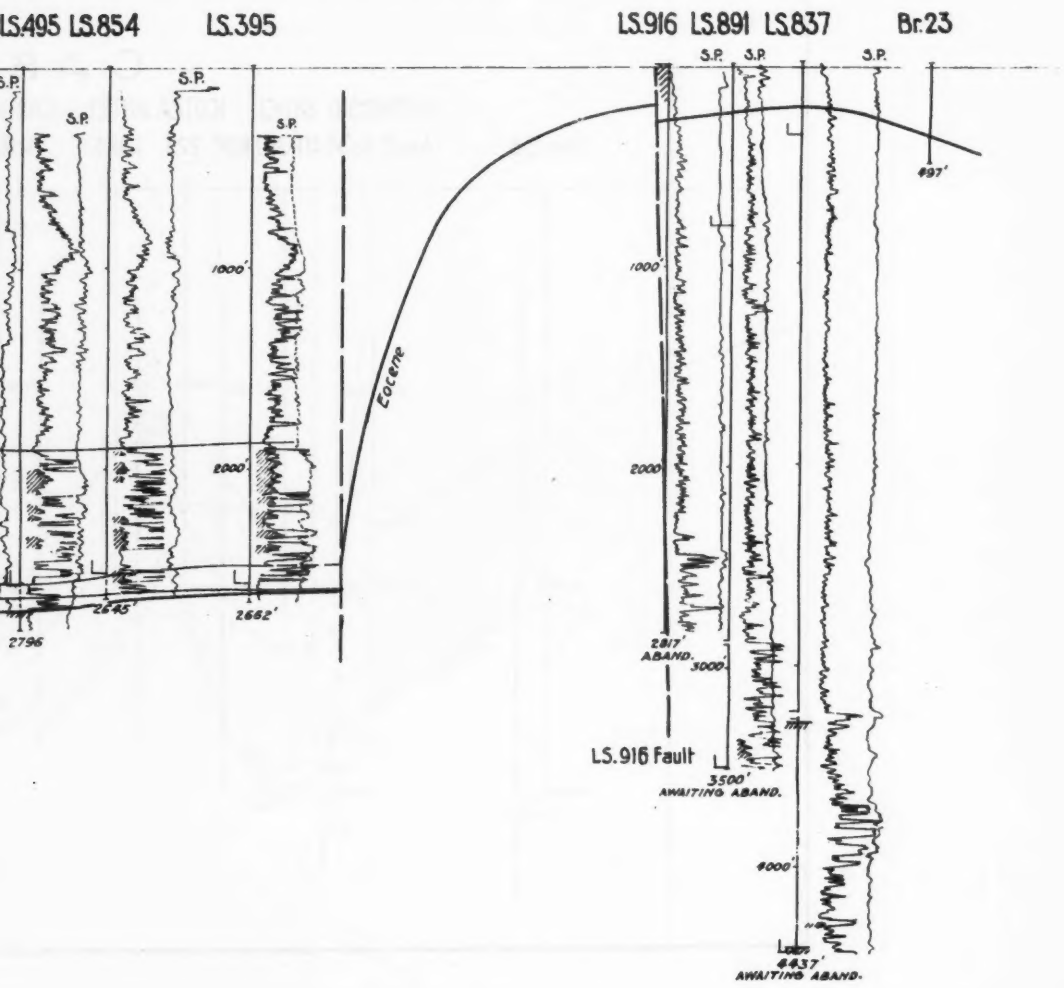


izontal, 1:50,000; vertical, 1:10,000. (U) H.O.Z.: (Upper) Heavy Oil zone. L.O.Z.: Light Oil zone. L.R.: La Rosa formation.

PUEBLO VIEJO UPLIFT



Company which holds a narrow strip of concessions along the shore (Fig. 3), and by the Creole Petroleum Corporation whose concessions extend far over and in places across the lake.

It is clear that a comprehensive study of the reservoir should include the fields operated by the three companies. Information is exchanged among the competing companies, and all general maps of the Bolivar Coast fields drawn by the exploitation engineers of the Venezuelan Oil Concessions Limited are based on data from the whole producing area. This is also the case with the original maps, which are used for publication in the present symposium (Fig. 3). They contain a structural interpretation of the whole reservoir and, although it is impossible to print them completely on account of limitation of space, a large part of the lake area is included, and it is hoped that this will help the reader to connect the land area discussed here with the lake area described in the paper prepared by the Creole Petroleum Corporation.

STRATIGRAPHY

The most important stratigraphical feature in the Bolivar Coast fields is the unconformity along which the Miocene transgresses onto the Eocene, since it played a major part in the oil accumulation.

Much attention has been given the stratigraphy of the Miocene, from which 99 per cent of the production of the Venezuelan Oil Concessions Limited in the Bolivar Coast fields is derived. The Eocene, on the contrary, was explored by comparatively few wells, notably by the Pueblo Viejo wells and recently by deep tests in the Cabimas field (R–801: 13,034 feet), and on the Curazao anticline (CC–2A: 15,106 feet). The correlation of the formations throughout the fields is assembled in Table III. Type logs of the producing formations accompany the discussions of the various fields (Figs. 7–11).

EOCENE

The Eocene of the Bolivar Coast area is subdivided into three formations, from top to bottom: Mene Grande formation, upper Micaceous sandstone,[7] and lower Micaceous sandstone.[7]

Lower Micaceous sandstone.—The lower Micaceous sandstone is a monotonous, thick series of dark gray to black, carbonaceous and micaceous sandy shales interbedded with micaceous sandstones. A few outstanding sandstone bodies have been recognized in this formation. As an example, may be cited the Pueblo Viejo Main sandstone (Fig. 10), which is situated well below the top of the formation and produces oil in the Pueblo Viejo field. It is fine- to coarse-grained, in places pebbly, quartzitic, and has little porosity and permeability.

The lower Micaceous sandstone is the approximate equivalent of the Misoa-Trujillo formation of the Mene Grande field. This predominantly sandy formation

[7] These formation names are not very satisfactory and should be replaced as soon as good type localities and definitions can be agreed on.

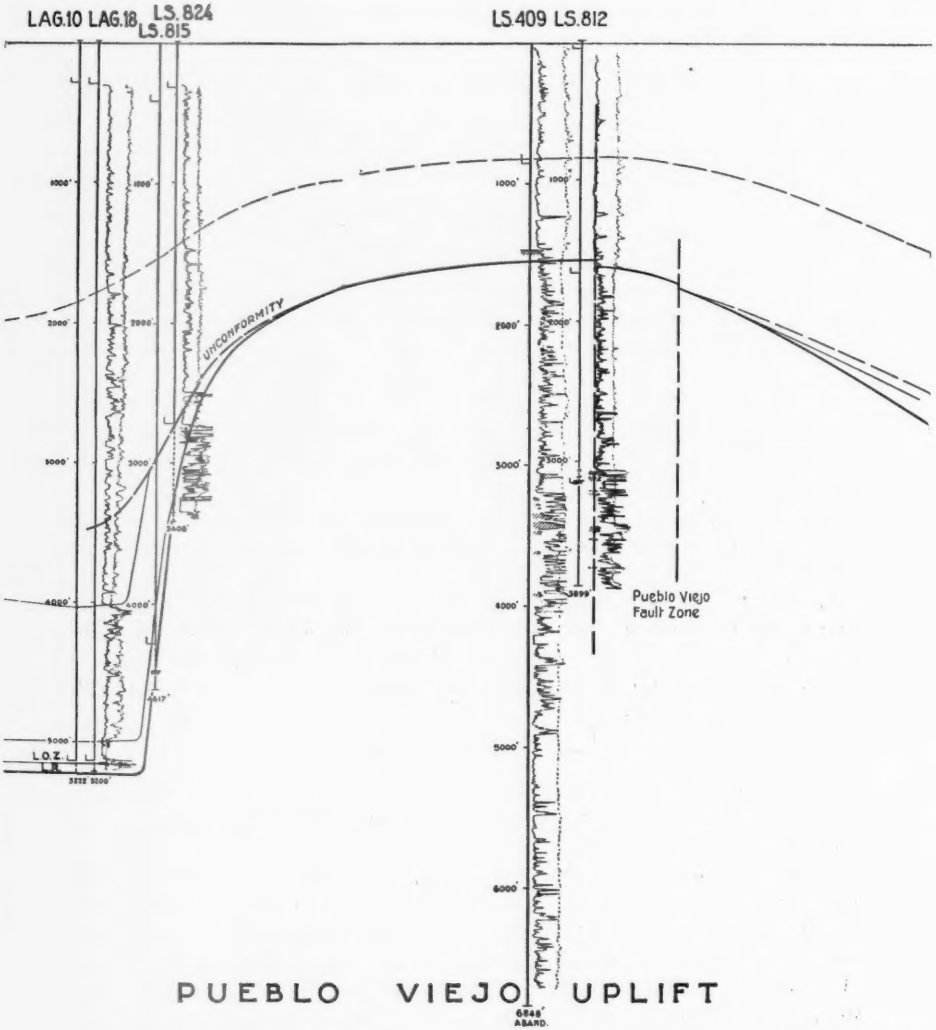
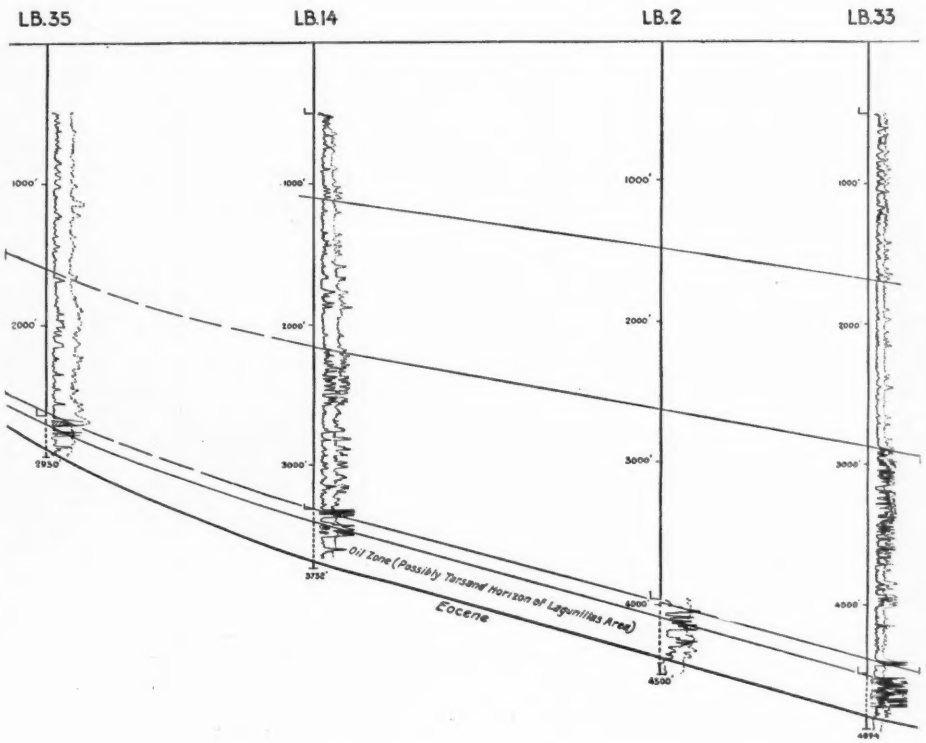


FIG. 6.—Section C through Bolivar Coast fields (Pueblo Viejo to Bachaquero), by G. Dickinson. Scale:



BACHAQUERO FIELD

horizontal, 1:73,000; vertical, 1:14,200; both approximate. L.O.Z.: Light Oil zone. L.H.: La Rosa formation.

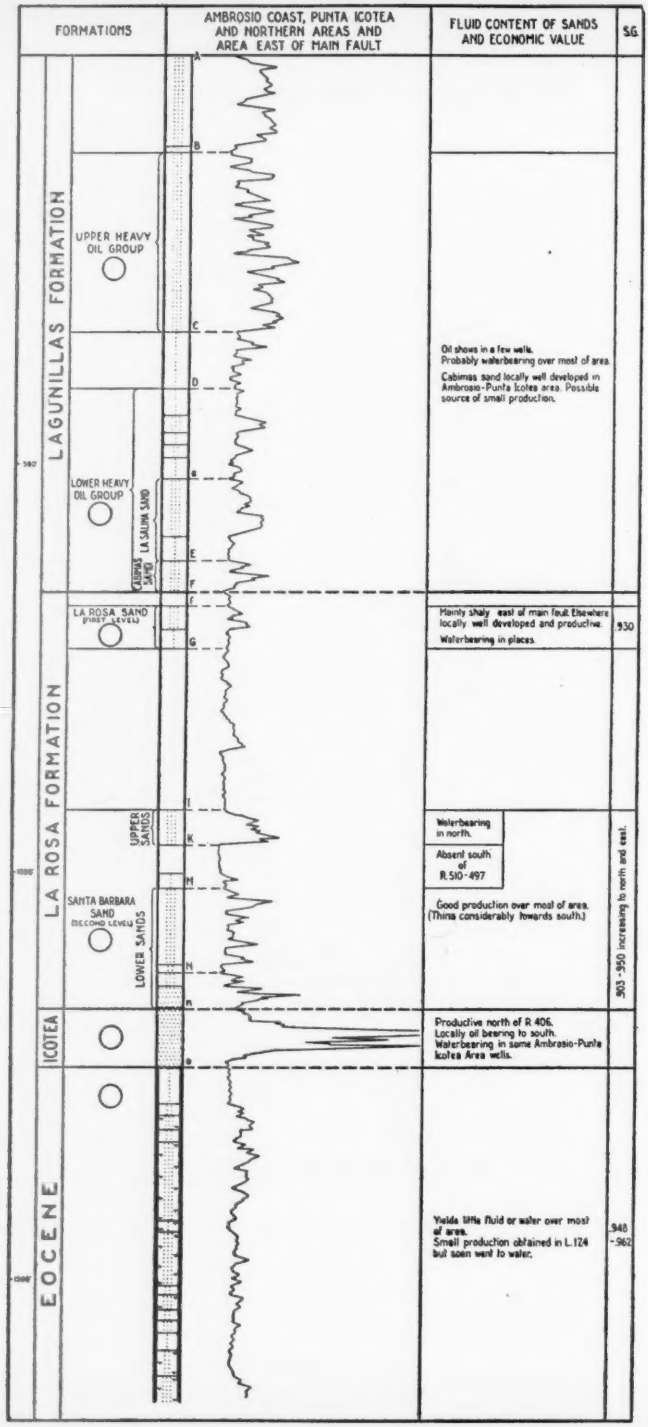


FIG. 7a.—Type section of producing formations in Cabimas field. Northern area.

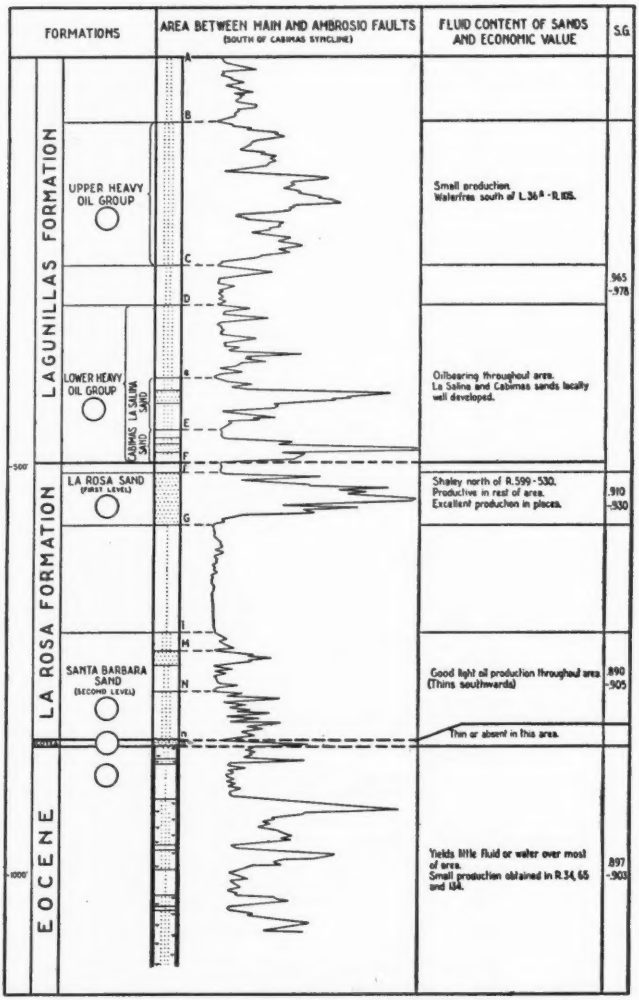


FIG. 7b.—Type section of producing formations in Cabimas field. Circles indicate productive zones; letters indicate marker horizons used for local correlation. Upper Sta. Bárbara sand is missing in area between Main and Ambrosio faults.

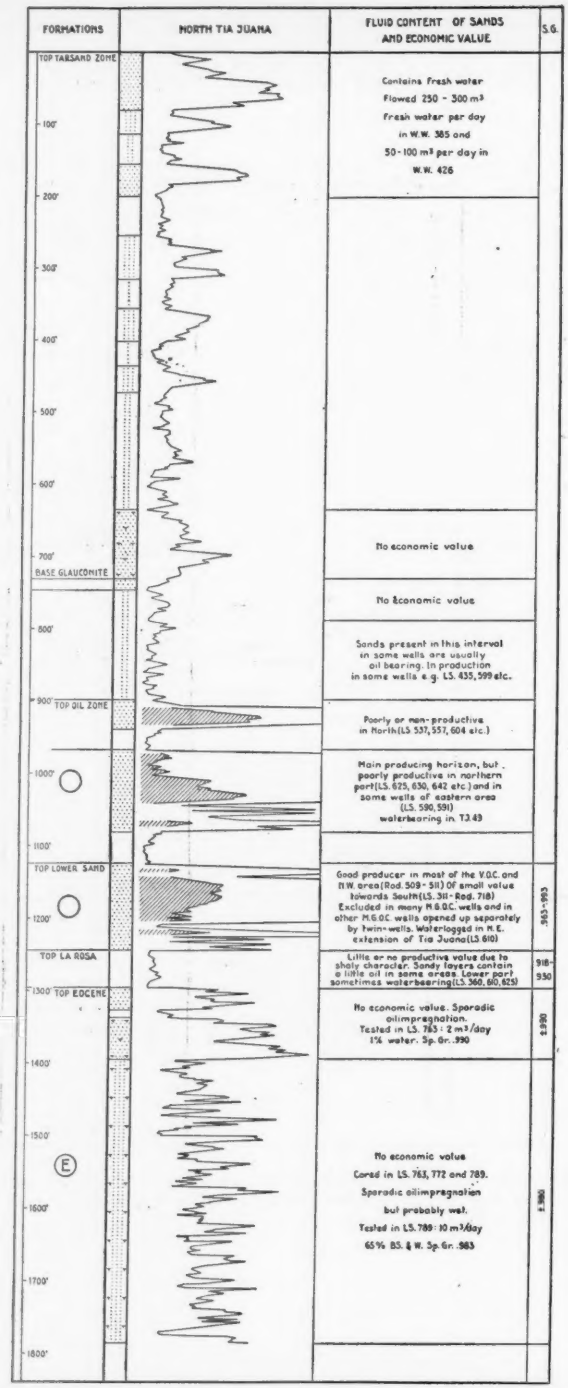


FIG. 8.—Type section of producing formations in northern Tia Juana field. Includes Eocene, La Rosa, and Lagunillas formations. Circles indicate producing zones.

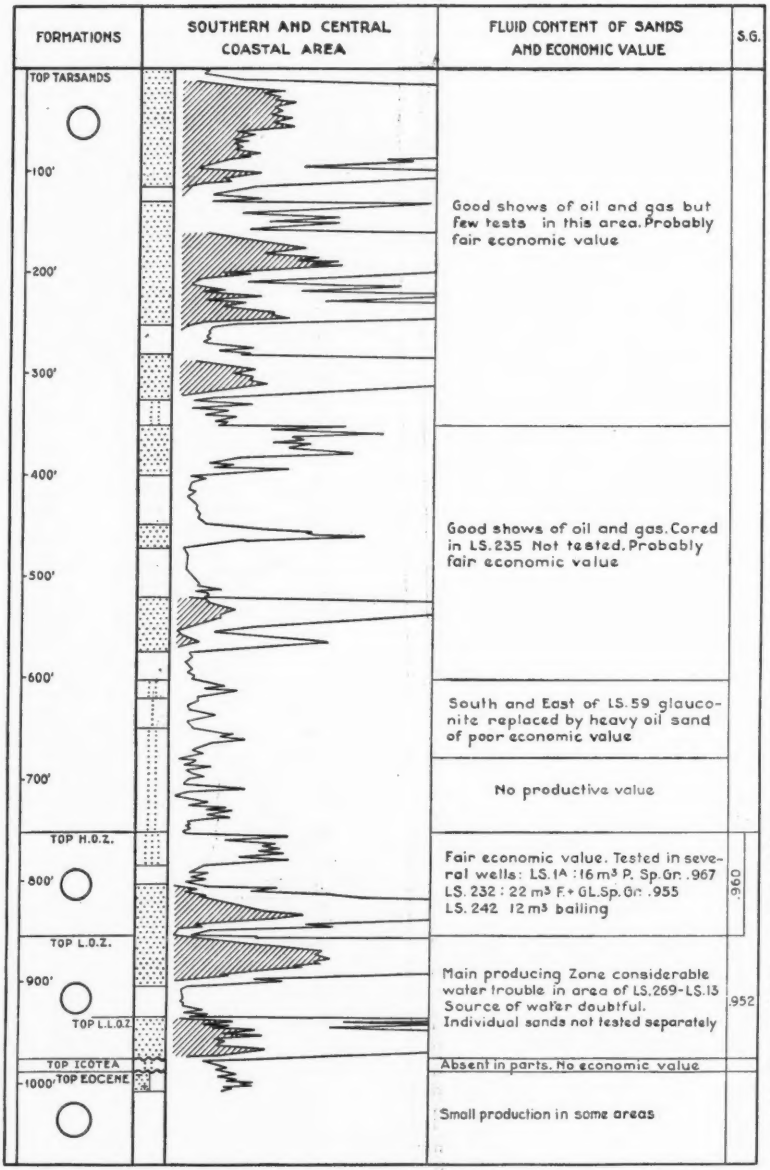

FORMATIONS
SOUTHERN AND CENTRAL COASTAL AREA
FLUID CONTENT OF SANDS AND ECONOMIC VALUE
S.G.
TOP TARSANDS
100'
200'
300'
400'
500'
600'
700'
TOP H.O.Z.
800'
TOP L.O.Z.
900'
TOP L.L.O.Z.
TOP ICOTEA
1000'
TOP EOCENE
Good shows of oil and gas but few tests in this area. Probably fair economic value
Good shows of oil and gas. Cored in LS.235 Not tested. Probably fair economic value
South and East of LS.59 glauconite replaced by heavy oil sand of poor economic value
No productive value
Fair economic value. Tested in several wells: LS.1A : 16 m³ P. Sp.Gr. .967
LS. 232 : 22 m³ F.+ GL.Sp.Gr. .955
LS. 242 12 m³ bailing
.960
Main producing Zone considerable water trouble in area of LS.269-LS.13
Source of water doubtful.
Individual sands not tested separately
.952
Absent in parts. No economic value
Small production in some areas

FIG. 9.—Type section of producing formations of Lagunillas field. H.O.Z.: Heavy Oil zone. L.O.Z.: Light Oil zone. L.L.O.Z.: Lower Light Oil zone. Circles indicate producing zones. La Rosa formation absent in this section.

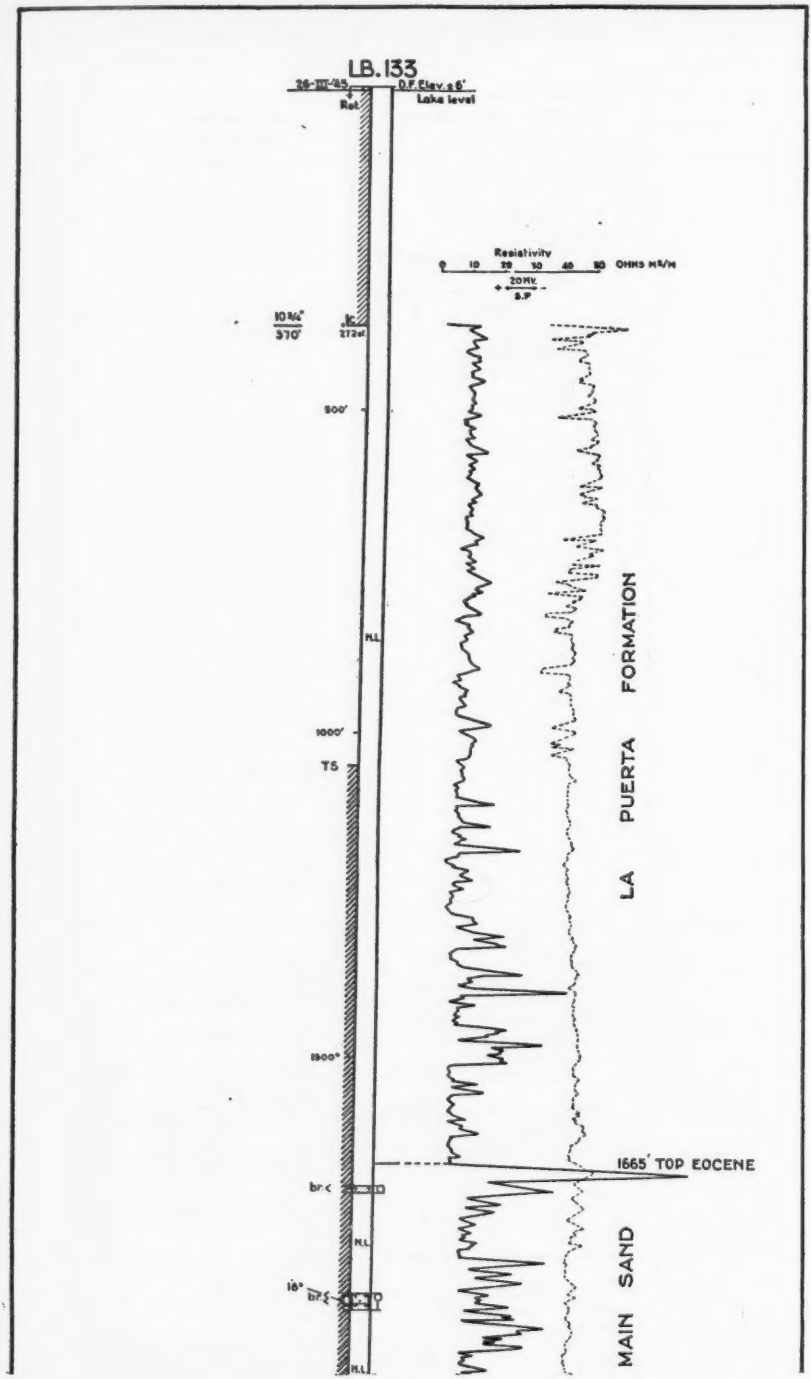
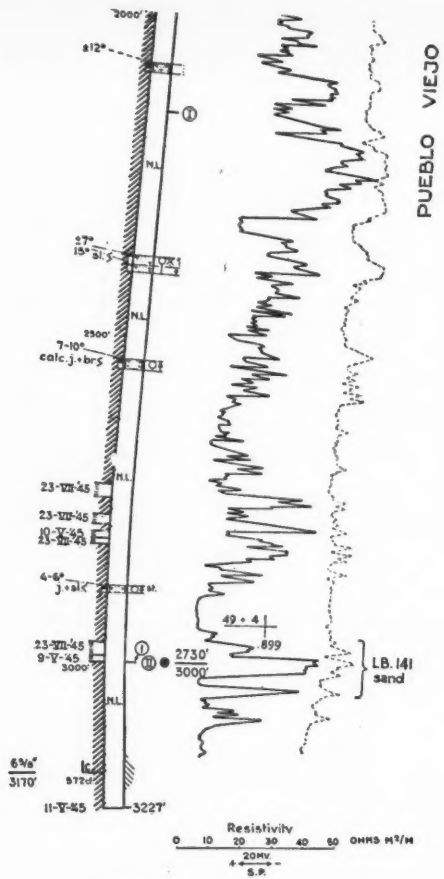


FIG. 10.—Log of Pueblo



LB. 133

① 2026'/2145' DST/62 min. Flowed slightly saline water at rate of ±30M³, little gas. Bean 1/2"

③ 2990'/3000' DST/2 1/2 hrs. Flowed ±150M³/day oil S.G. .886, cut 0.5% sand, 0.3% B.S. & W. Bean 1/2"

① 2800'/3000' (F) 82 + 7 | 3 / 29 + 6 | 1 1/2 / .885

POROSITY AND PERMEABILITY DETERMINATION

DEPTH OF SAMPLE	DRILLING FLUID USED	POROSITY %	PERMEABILITY VERT MD.	PERMEABILITY HORIZ MD.	SATURATION OIL %	SATURATION WTR %	SALINITY MG. CL. P.L.	SOLUBLE IN 15% HCL %	REFR. INDEX REDUCED OIL 30° C.	ESTIMATED SPEC. GRAV. AT 60° F
1702'-1712'	Clay mud	10 6	2.6	3.2	18.6	35.2	4750		1.5418	
" "	" "	12 2	12	11	19.3	30.6	4000		1.5410	
" "	" "	12 0	3.6	2.8	N.D	ND	ND		1.5418	
1867'-1882'	" "	12.2	1.7	1.8	ND	ND	ND		ND (trace)	.950-.970
" "	" "	12.4	1.2	1 2	0.9	69.0	5890		" "	
1882'-1891'	" "	10.5	0.7	0.9	4.2	56.4	2040		1.5320	
" "	" "	10.3	3.7	4.3	6.4	49.0	2100		1.5352	
2076'-2089'	" "	12.0	0.5	0.6	ND					
" "	" "	10.3	0.2	0.3	ND					
2374'-2390'	" "	11.6	0 2	0.3	ND					
2534'-2549'	" "	11.2	0.4	0.8	21.4	46.7	2280		1.5208	.926

Viejo well LB-133.

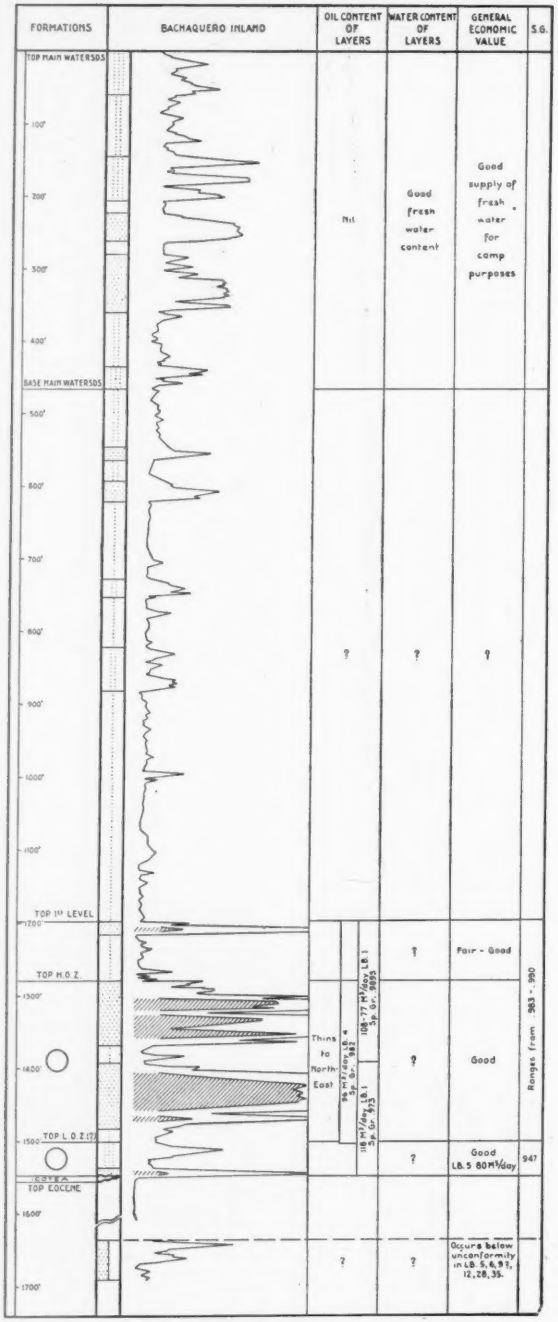
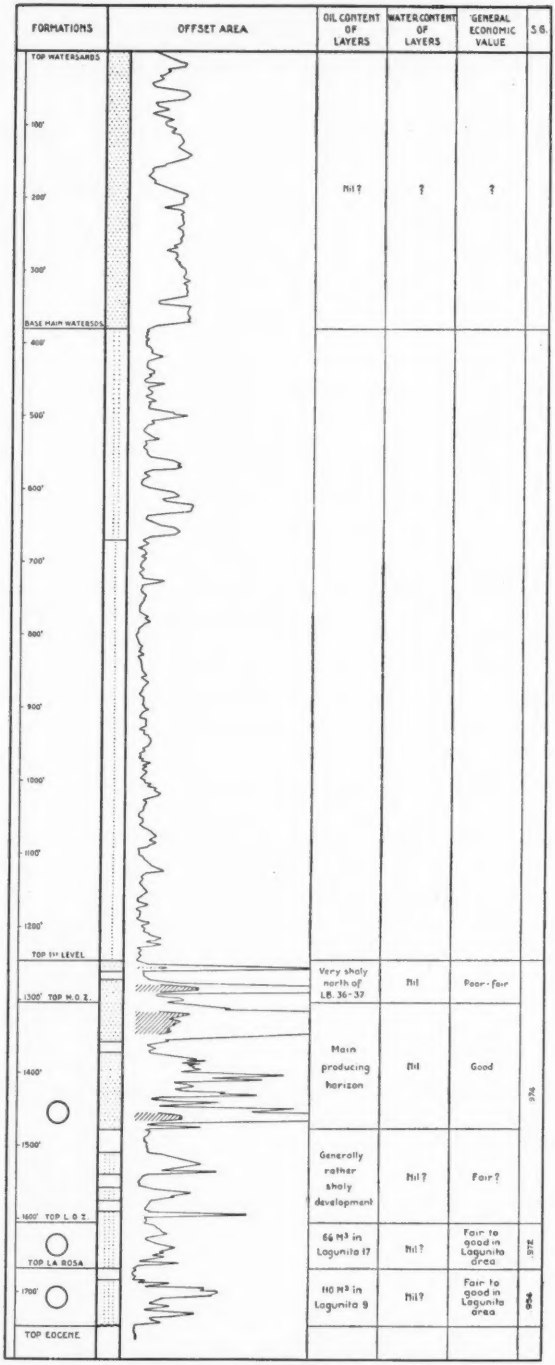


FIG. 11.—Type sections of producing formations of Bachaquero field. Includes Eocene, Icotea, zones. L.O.Z.: Light Oil zone;



La Rosa, and Lagunillas formations and lower part of La Puerta formation. Circles indicate producing H.O.Z.: Heavy Oil zone.

TABLE III

STRATIGRAPHIC CORRELATION THROUGHOUT BOLIVAR COAST FIELDS
(According to G. Dickinson)

System	*Formation*	*Cabimas*	*Tia Juana*	*Lagunillas*	*Pueblo Viejo*	*Bachaquero*
UPPER MIOCENE	La Puerta	La Puerta	La Puerta	La Puerta	La Puerta	La Puerta
MIDDLE MIOCENE	Lagunillas	Lagunillas Tar sands	Lagunillas Tar sands	Lagunillas Tar sands	Gap	Bachaquero sand
			Glauconite zone	Glauconite zone		Light Oil zone
		First fossils	First fossils	First fossils		
		Key Coal	Upper sand	Heavy Oil zone		Absent or possibly represented by Light Oil zone
		Upper Heavy Oil group		Light Oil zone		
		Shale				
		Lower Heavy Oil group	Lower sand	Lower Light Oil zone		
LOWER MIOCENE	La Rosa	Upper La Rosa: La Rosa sand	? ? La Rosa	? ? La Rosa		La Rosa
		Upper La Rosa: Intermediate sand				
		Lower La Rosa: Upper → Sta. Bárbara sand; Lower				
(OLIGOCENE?)	Icotea	Absent in places	Absent in places	Absent in places		Absent in places
	Mene Grande	Gap	Gap	Gap		Mene Grande formation
EOCENE	Upper Micaceous sandstone	Upper Micaceous sandstone	Upper Micaceous sandstone	Upper Micaceous sandstone		Upper Micaceous sandstone
	Lower Micaceous sandstone	Lower Micaceous sandstone	Lower Micaceous sandstone	Lower Micaceous sandstone	Lower Micaceous sandstone	Lower Micaceous sandstone

grades into the lower Micaceous sandstone in the region between Mene Grande and Bachaquero. The faunas of both formations are poor, and do not permit a direct age determination. Regional correlation, however, suggests middle Eocene age.

The total thickness of the lower Micaceous sandstone in the Bolivar Coast fields is unknown, but must amount to more than 10,000 feet. The Venezuelan Oil Concessions Ltd. has substantial production from this formation only at Pueblo Viejo but large amounts of oil are obtained from sand bodies of similar stratigraphic position on the Lake concessions of the Creole Petroleum Corporation. Poor showings in the formation were reported in the Cabimas deep test.

Upper Micaceous sandstone.—The upper Micaceous sandstone is a series of micaceous shales, sandy shales, and sandstones, which overlies the lower Micaceous sandstone with a transition. It corresponds approximately with the Paují formation of the Mene Grande area. Between Mene Grande and Cabimas a gradual change occurs from a shaly facies in the southeast to a sandy-shaly development in the northwest.

Several subdivisions based on microfaunas help to establish the structure of the Eocene beneath the Miocene transgression.

About 300 feet of oil-impregnated sandstone belonging to this formation have been found in some wells of the Lagunillas field. This sandstone contributes little production, however. Small production was also obtained from the upper Micaceous sandstone in the early Cabimas wells, but this oil was usually produced together with the Miocene oil.

The total thickness of the formation in Lagunillas amounts to about 2,300 feet.

Mene Grande formation.—The type locality of the Mene Grande formation is in the Mene Grande field of the Caribbean Petroleum Company. On the Bolivar Coast it is present only in the Bachaquero field, where it consists of 400–500 feet of shales in the middle of the Eocene-Bachaquero syncline just beneath the Miocene unconformity. This thickness represents the basal part of the formation, which is easily recognized because of its typical fauna. Paleontological studies suggest a high middle Eocene age.

PRE-MIOCENE PENEPLAIN

Most wells in the Bolivar Coast fields are drilled only a few feet into the Eocene, mainly in order to make sure that the whole Miocene has been perforated. It is thus possible to draw a fairly accurate contour map of the Miocene unconformity (Fig. 3). Many cores and dip-meter readings were taken in the Eocene and have been used to map the distribution of the Eocene formations below the unconformity and to determine the character of the structures in the Eocene.

At the time of the Miocene transgression the Eocene had already been folded, faulted, and eroded. The older beds were exposed on the anticlines, for instance, on the Pueblo Viejo anticline which formed an outstanding ridge of hard sand-

stones. As a whole, however, the erosional surface must have been a peneplain rather similar to the one exposed at present in the northwestern Bolivar District, north of the Cabimas field.

MIOCENE

The Miocene is subdivided into four formations, from top to bottom: La Puerta, Lagunillas, La Rosa, and Icotea.[8] These in turn are subdivided in the various fields for purposes of local correlation, as shown in Table III. A short description of the different formations follows, but for more detailed studies we refer to the papers by M. W. Haas and R. G. Hubman,[9] G. E. Manger,[10] and W. S. Hoffmeister.[11]

Some remarks on the age of these formations may be added. Only the La Rosa and Lagunillas formations contain faunas which allow age determinations. Formerly, some controversy reigned regarding the age of the La Rosa formation, which was placed alternately in the lower Miocene or the upper Oligocene but to-day the Miocene age of the formation seems to be generally accepted. Very few fossils were found in the Icotea formation, which is usually assigned to the Oligocene on the strength of its position below the La Rosa formation.

For the purpose of this paper we have grouped these formations under the heading Miocene, because we believe this to be the age of the La Rosa formation and because we have no definite proof that the Icotea formation belongs to the Oligocene. In addition, the beds from the base of the Icotea to the top of the La Puerta represent one cycle of sedimentation intercalated between two phases of strong orogenic movements, and should be discussed as a whole. It should be borne in mind, however, that this cycle may already have started in the Oligocene.

Icotea formation.—The Icotea formation consists mostly of non-stratified, white sandy clay or clayey sandstone, in places some green sandstone or mottled clay at the base. The scarcity of fossils and the abundance of sideritic spherulites are characteristic. The origin of the formation is conjectural; possibly deposition of eolian material took place in very shallow water under brackish and perhaps reducing conditions.

The greatest thickness is found in the Cabimas field (130 feet) and here a coaly shale forms the top of the formation. The type locality, Punta Icotea, is situated in this field. The formation decreases in thickness in a southerly direction

[8] Although Icotea is the accustomed spelling it would be more correct to use Hicotea or Jicotea, the Latin-American word for land turtle.

[9] M. W. Haas and R. G. Hubman, "Notes on Stratigraphy of the Bolivar Coastal Fields, Maracaibo Basin, Venezuela," *Bol. Geologia y Mineria*, Tomo I, Nos. 2–4. Caracas (1938).

[10] G. E. Manger, "Notes on the Stratigraphy of the Younger Tertiary Formations of the Bolivar Coastal District, State of Zulia, Venezuela," *ibid.*, Tomo II, Nos. 2–4. Caracas (1938).

[11] W. S. Hoffmeister, "Aspect and Zonation of the Molluscan Fauna in the La Rosa and Lagunillas Formations, Bolivar Coastal Fields, Venezuela," *ibid.*

and is absent in the southern part of the Cabimas field. It occurs also in parts of the Tia Juana field (20 feet), the northern Lagunillas field (25 feet) and in the western half of the Bachaquero field.

Some oil is produced from this formation in the Cabimas field.

La Rosa formation.—The type locality of the La Rosa formation is the Cabimas field (formerly La Rosa field), where the formation reaches its maximum thickness (750 feet) in the Icotea syncline. It decreases in a short distance southward to approximately 130 feet and less in Tia Juana, 130 feet and less in North Lagunillas, and approximately 90 feet in Bachaquero.

The formation lies conformably on the Icotea formation where this is present, but it extends much farther than the Icotea and transgresses onto the Eocene. The sharp lithological change from the Icotea to the La Rosa indicates some interruption in sedimentation, which is confirmed by the presence of a coaly shale at the top of the Icotea in the Cabimas field.

The La Rosa formation is absent over many areas of the fields and apparently was deposited only in the lower parts of the region. In Cabimas it can be subdivided on paleontological evidence into upper and lower La Rosa, but this subdivision can be followed only as far as Tia Juana. Farther south the Lower La Rosa seems to be absent, probably on account of progressive transgression.

The La Rosa formation produces oil in the Cabimas field, in Tia Juana, in North and South Lagunillas, and in part of the Bachaquero field.

The lower La Rosa of Cabimas is generally composed of gray sands and sandy shales, with green shale and sand intercalations. The faunal characteristics are stunted foraminifera and a macrofauna which is poor in comparison with that found in the upper La Rosa. Biological conditions were still unfavorable for the development of a good marine fauna, but better than during Icotea time.[12] The lower La Rosa contains the Santa Bárbara sands in its lower part. They are in places subdivided by a shale wedge into an upper and lower sand. Good light oil is produced from the Santa Bárbara sands.

The upper La Rosa of Cabimas consists mainly of greenish shales and sands. It is characterized by the presence of a rich, marine fauna which proves that the area of the Bolivar Coast fields was connected with the open sea.

The upper La Rosa apparently extends farther over the Eocene than the lower La Rosa. Between Tia Juana and Bachaquero it is probably replaced laterally by sediments of a more terrigenous character, which can not be separated from the similar sediments of the Lagunillas formation.

In some parts of Cabimas field the upper La Rosa contains a thin sand at its base, which is of small importance for production (Intermediate sand). The upper half of the formation is the so-called La Rosa sand, from which excellent production was obtained in some parts of the Cabimas field, while in others it is shaly and accordingly less productive.

[12] For details on the faunal zones, see W. S. Hoffmeister, *op. cit.*

Lagunillas formation.—The type locality of the Lagunillas formation is the Lagunillas field, where the formation consists mainly of sands and variously colored interlaminated shales and is approximately 1,000 feet thick.

The lower part of the formation is formed by a group of lenticular sands, which are 200–230 feet thick. They are the main oil reservoir in the Tia Juana field, where an upper and lower sand are recognized, and in the Lagunillas field where the sands are subdivided into Heavy Oil zone, Light oil zone, and lower Light Oil zone in accordance with small differences in the gravity of the oil which they contain.

These sands are overlain by a zone of fissile shales and interlaminated sands, which contain faunas of brackish, in rare cases marine character. The thickness of this zone is about 90 feet in the Lagunillas field. At its top a discontinuous, lenticular fossil horizon occurs over large areas and has been used for correlation under the name of First Fossil horizon. In Cabimas it is underlain by a lignite bed, while in Tia Juana and most parts of the Lagunillas field a glauconite zone is found either just above the fossil horizon or a little higher.

The remainder of the formation is sandy and lignites are fairly common. In Lagunillas the sands of this upper part of the formation contain very heavy oil and are therefore called the Lagunillas Tar sands. They are thought to correspond with the productive Bachaquero sands in the Bachaquero field but this correlation is conjectural.

The Lagunillas formation rests conformably on the La Rosa formation where present. Elsewhere, it transgresses over the Eocene and thus extends over larger areas than the La Rosa formation. The change from the marine facies of the La Rosa to the more brackish facies of the Lagunillas formation is sudden but there are a few thin marine recurrences in the latter. Lignites in the upper part of the Lagunillas formation suggest a brackish-water facies.

La Puerta formation.—The La Puerta formation, which is named after a locality in the State of Falcón, is composed mainly of mottled clays, silt, and sands. The upper part contains water-bearing sands in Lagunillas and Bachaquero.

The La Puerta formation rests conformably and transitionally on the Lagunillas formation. On the Pueblo Viejo anticline, which was the highest part of the pre-Miocene peneplain, the La Puerta formation transgresses over the Eocene. In this area oil showings were observed in it, but no oil was produced.

Its maximum thickness in the Lagunillas and Bachaquero fields is 3,500 feet but it thickens considerably downdip from the producing areas.

Conclusions.—In conclusion it can be said that the Miocene transgresses progressively over the pre-Miocene erosional surface. The older formations filled the topographical depressions on this surface, while the younger formations transgressed farther over the Eocene, presumably on account of continuous subsidence. Thus, most horizons were sealed off along progressive shore lines, a fact which was of primary importance for the accumulation of oil.

Subsidence was, however, not regular and not of the same magnitude over the

whole Bolivar Coast. There are areas where the Icotea formation, for instance, is present, but the La Rosa is missing. The marine invasion of the upper La Rosa presumably indicates a more rapid rate of subsidence which opened the Maracaibo Basin to the sea. During La Rosa times deposition decreased from Cabimas toward Lagunillas and as the facies remains much the same over the whole area, we can assume that subsidence was greater in the north than in the south. The whole Miocene sedimentation took place in shallow water with many currents and was very lenticular, with local unconformities and lateral changes from marine to brackish-water facies. The Eocene uplifts were probably a source for the Miocene sands.

POST-MIOCENE DEVELOPMENT

After deposition of the La Puerta formation sedimentation was interrupted and major folding set in. The existing Eocene structures were rejuvenated and accentuated.

A period of uplift and erosion must have followed, and thereafter the lower parts of the Bolivar District were covered by Lake Maracaibo in which were formed very young, predominantly sandy beds known as the Milagro formation[13] (Pliocene or Pleistocene). These beds are exposed north of Cabimas along the lake shore, and cover the areas of the fields. Their thickness may amount to about 300 feet. The lake receded again after the deposition of the Milagro formation and the area of the Bolivar Coast fields was then exposed to the levelling actions of erosion and alluvial sedimentation.

STRUCTURE

(Figs. 3–6)

The structure of the Bolivar Coast fields can be briefly described as two broad synclinoria separated by the narrow Pueblo Viejo uplift and affected by a south-southeast striking fault system. The northern or Cabimas-Lagunillas synclinorium includes the Cabimas, Tia Juana, and Lagunillas fields. It is subdivided by two very gentle southwest-plunging uplifts at Punta Benitez and Tia Juana into the flat synclinal area of Lagunillas and the more accentuated synclinal zone of Cabimas.

The uplift at Punta Benitez probably represents the plunge of the Curazao anticline, which is exposed east of Cabimas and turns sharply southwest out of a west-northwest strike. The Punta Benitez and Tia Juana uplifts influence the Miocene unconformity only slightly, and no further movement took place after the deposition of the Miocene.

The Lagunillas synclinal area is well expressed in the Eocene, where the youngest formations are found only in its deepest part adjacent to the Pueblo

[13] See H. D. Hedberg and L. C. Sass, *op. cit.*

Viejo anticline. Above the Miocene unconformity the syncline is so wide that it can be considered as a southwest-dipping monocline.

The Cabimas synclinal area is subdivided into the Cabimas and Ambrosio synclines by the narrow Icotea anticline which had a marked influence on the Miocene deposition and was accentuated again in the last phase of folding.

The Cabimas synclinal zone is situated between the Eocene uplift of Curazao-Punta Benitez in the southeast and the high Eocene area in the northwestern Bolivar District.

The Pueblo Viejo anticline is the highest structure in the Bolivar Coast and the oldest Eocene sediments known in the fields are found on it just below the Miocene transgression. During most of the Miocene this uplift was not submerged and it separated the Lagunillas area from the Bachaquero area, a fact which is made plain by the different stratigraphical development in these fields. During and after deposition of the La Puerta formation the anticline was accentuated by Andean movements.

The Pueblo Viejo anticline plunges southwest and is a continuation of the East Lagunillas anticline exposed farther northeast. It has a very steep northwest flank, which is possibly associated with some thrust movements. The south flank is less inclined.

Southeast of the Pueblo Viejo anticline and stretching as far as the Mene Grande field is another wide synclinal zone, called Bachaquero or Machango-Sibaragua synclinorium. It deepens strongly in a southwesterly direction, whereas on the northeast it is surrounded by the Eocene uplifts of the Pueblo Viejo-Misoa arch.

The Bachaquero field is situated in this synclinorium on the southeast flank of the Pueblo Viejo anticline. The synclinorium is so wide here that the structure of the field is monoclinal.

A south-southeast-striking fault system has been fairly well established in the Lagunillas-Cabimas synclinorium. The Icotea fault, the Cabimas Main fault, the Cabimas Boundary fault and the Lagunillas fault belong to it, to mention only the most important. Movements along these faults occurred probably twice, before and after the deposition of the Miocene. On the first occasion steeply dipping step faults were formed, each causing a considerable downthrow toward the east. The faults were revived during the latest tectonical movements, but this time the displacement was apparently mainly horizontal, for instance on the Pueblo Viejo anticline.

ACCUMULATION

Although very large quantities of Eocene oil are being produced from the Creole's concessions in the lake, oil accumulation in the Eocene has so far been of minor importance in the Bolivar Coast fields of the Venezuelan Oil Concessions Limited.

The only Eocene oil produced separately comes from the Pueblo Viejo field.

Accumulation took place on the crest of an anticline, but is affected by cross faults and overlap of the Miocene. As far as can be ascertained from cores, the oil appears to occur in sandstones of low porosity and permeability, and the producing reservoirs are probably fractures.

Small accumulations also exist in Cabimas, southern Tia Juana, Lagunillas, and Bachaquero.

The accumulation in the Miocene is due to combinations of favorable structural and stratigraphical conditions. The oil is found in the wide synclinal areas between the Eocene uplifts where it has migrated updip in the Miocene and accumulated just above the unconformity. The oil occurs in gradually younger deposits from Cabimas to Bachaquero, due to the progressive transgression of the Miocene. The most important causes for trapping are facies changes involving decrease of permeability and porosity, lenticularity of the sands and their wedging against the Eocene, and faulting which for instance influences accumulation in the Cabimas field, where the sands are water-bearing east of the so-called Boundary fault.

In the Cabimas field the specific gravity of the oil decreases gradually down structure. This is apparently connected with a further cause for trapping, namely, the clogging of sands by heavy residue near the outcrop of the oil sands. Seepages of heavy oil are found there along the outcrops of the La Rosa formation which is productive a short distance downdip.

Gravity stratification of the oil seems to occur in the Miocene of all fields. The older formations probably contain lighter oil than the younger ones, in any locality, but as the different sands are normally produced together there is little information available on this point.

CABIMAS FIELD

SITUATION AND DEVELOPMENT

The Cabimas field of the Venezuelan Oil Concessions Limited is the northernmost of the Bolivar Coast fields. It is situated partly in the swampy alluvial plain of Rio El Mene, partly on dry, slightly elevated level terrane stretching from Punta Icotea to the Eocene outcrops east of the field, and partly in the swamps bordering the shore of Lake Maracaibo southeast of Punta Icotea. Some drainage work was necessary in the northern part of the field.

Drilling was commenced in this area in 1913, mainly because of oil seepages north and east of the field. The discovery well was a small pumper only, but it revealed the first major producing field in Venezuela and was the forerunner of further prolific fields in the Maracaibo Basin. Development of the field went on until July, 1943, when drilling was suspended. The most spectacular well in this field was Barroso 2 (renamed R–4) which blew out and flowed at the rate of approximately 10,000 barrels per day for 9 days, until it sanded up.

On March 5, 1929, the first electrical well log made outside of France was run by the Schlumberger Company in the Venezuela Oil Concessions' well R–216. It

was a resistivity survey and gave encouraging results. By 1930 electrical logging became the general practice in the oil fields of the Royal Dutch-Shell group in the Maracaibo Basin, long before the method was generally applied and its value recognized in the United States.

To-day the proved area of the Venezuelan Oil Concessions' Cabimas field has an extension of 11.5 km. (7 miles) north and south and 7 km. (4.3 miles) east and west. The reservoir reaches far under Lake Maracaibo, however, and the field is continuous with the Ambrosio, La Rosa, and Punta Benitez fields of the Mene Grande Oil Company and the Creole Petroleum Corporation. An offset agreement with these companies controls the exploitation along the lake shore.

OIL AND GAS RESERVOIR

(Fig. 7)

The main production of the Cabimas field is derived from the Miocene formations. Some oil has been produced from the top of the Eocene in the central part of the field, but it is insignificant compared with that from the Miocene.

In the Miocene the following producing sands are recognized from top to bottom.

Upper Heavy Oil group Lower Heavy Oil group	Gravity of oil varies from 15.1° to 13.2° A.P.I. (S.G. 0.965–0.978)
La Rosa sand	Gravity ranges from 24° to 20.5° A.P.I. (S.G. 0.910–0.931)
Santa Barbara sands	Gravity ranges from 27.5° to 24.8° A.P.I. (S.G. 0.899–0.905) in southern half of field, but increases to 15.9° (S.G. 0.960) in northern half where sands are still productive only 800 meters south of seepages accompanying their outcrops
Icotea sand	Productive in northern half of field, where gravity varies from 22.3° to 19° A.P.I. (S.G. 0.920–0.940)

In general the specific gravity of the oil decreases from top to bottom in the oil-bearing section. The small accumulations in the Eocene are an exception, as the Eocene oil is in some places heavier than the Miocene oil. This may be due to inspissation.

The various sands are usually produced together. They are unconsolidated and the effective porosity amounts to 25 per cent at least.

The total thickness of productive sand, comprising the lower Lagunillas, La Rosa, and Santa Bárbara sands, is approximately 80 feet over an area of more than 5,000 hectares (12,350 acres). Water is not a serious problem in this field, and is found only in certain areas where it is probably connected with faulting.

DRILLING AND COMPLETION PRACTICE

At present there is no drilling in the Cabimas field. A deep test was drilled during 1944 and the first half of 1945. It reached a depth of 13,034 feet and was at that time the deepest well in South America.

When exploitation drilling was last carried out, wells were drilled with a Franks portable outfit, and depths varied between 1,000 feet and 2,500 feet. A

slim-hole technique was used, and wells were completed with an $8\frac{5}{8}$-inch surface string and $4\frac{1}{2}$-inch oil string.

Drilling times were very short because the formations are soft and the holes

TABLE IV

PRODUCTION STATISTICS OF CABIMAS FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1917–1922 inclusive	506,122
1923	2,287
1924	2,652,604
1925	4,152,682
1926	10,575,831
1927	10,249,854
1928	14,859,936
1929	21,845,701
1930	17,752,341
1931	13,537,939
1932	15,557,738
1933	14,939,654
1934	11,383,462
1935	8,728,614
1936	8,116,041
1937	8,200,150
1938	8,889,198
1939	8,693,902
1940	8,652,270
1941	8,332,134
1942	6,294,333[1]
1943	8,626,868
1944	7,990,707
1945	6,960,972
Total	227,501,340

[1] Production affected by adverse shipping situation.

PRODUCTION DURING DECEMBER, 1945

	Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*No. of Producing Wells*
Flowing	—	245	245	4
Gas lift	—	2,490	2,520	62
Pumping	—	15,120	15,120	525
Total	558,509	17,855	17,885	591

shallow—in the more recent drilling campaigns wells were completed in an average of 4–5 days. A $4\frac{1}{2}$-inch combination string with 0.012-inch gauge screen pipe was cemented through ports above the entire productive zone, and the wells were washed into production. Wells were generally completed with a light oil-base mud as circulating fluid, because of the possibility of damage to the low-pres-

sure formations and the difficulty of cleaning the screen when using clay muds.

Practically no coring has been carried out in recent wells, but ealier wells were cored fairly extensively. Correlation is now made entirely by means of Schlum-

TABLE V

CHARACTERISTICS OF CABIMAS CRUDE OIL

GENERAL	
Type	Asphaltic
Specific gravity	0.90 to 0.96
A.P.I. gravity range	25.7° to 15.9°
CRUDE OIL TAKEN FROM MAIN STORAGE TANK ON APRIL 2, 1945	
Specific gravity 60/60°F.	0.9252
A.P.I. gravity	21.4°
Color by reflected light	Black
Color by transmitted light	Dark brown
Viscosity Engler at 30°C.	14.3°
Viscosity Engler at 50°C.	5.71°
Flash point	Below 50°F.
Pour point test	Below 32°F.
Paraffine wax	0.72%
Setting point of paraffine wax	55°C.
Sulphur	1.8%
Initial boiling point	67°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945	
Yields by volume	
Gasoline	11.99%
Gas oil	10.41%
Fuel oil	76.60%
Properties of products	
Gasoline	
Specific gravity at 60°F.	0.752
Distilling up to 100°C. (A.S.T.M.)	18%
F.B.P. (A.S.T.M.)	205°C.
Octane number (C.F.R. motor method)	56
Gas oil	
Specific gravity at 60°F.	0.850
Distilling up to 300°C. (A.S.T.M.)	85%
Sulphur content	0.57%
Diesel index	49.7
Fuel oil	
Specific gravity at 60°F.	0.963
Viscosity Redwood I at 100°F.	3,540 sec.

berger electrical logging. Fairly good correlation was also obtained with gamma-ray logging through the casing of wells completed before Schlumberger logging was available.

PRODUCTION

A total of 818 wells had been drilled by the Venezuelan Oil Concessions in the Cabimas field to the end of 1945. At that time 591 were producing (flowing 4,

gaslift 62, pumping 525) and 129 had been abandoned. The remainder were not producing on account of high gas-oil ratios, mechanical condition, *et cetera*. In December, 1945, this field had a daily potential of 17,885 barrels and was producing to full capacity.

Initial production rates were low when the last exploitation wells were drilled in 1943, and averaged about 60 barrels per day, as the field was already in an advanced state of depletion. Most remaining locations are interspaced wells between existing drainage points with the object of obtaining maximum recovery. The field now has a low rate of decline, of the order of $1\frac{5}{8}$ per cent per month. The production history of the wells shows no water drive characteristics and production is of the dissolved gas-drive type.

TABLE VI

PRESSURE DECLINE IN SOME WELLS IN CABIMAS FIELD
(Pounds per square inch)

Well	*Final Depth (Feet)*	*Depth Top Second Level (Feet)*	*Pounds Pressure Top Second Level*	*Date Day Month Year*	*Pounds Pressure Top Second Level*	*Date Day Month Year*	*Total Recovery Barrels*
R-272	2,175	2,066	77	27-7-37	0	2-7-41	597,129
346	2,240	2,169	334	7-8-37	278	8-7-41	393,697
348	2,170	2,063	187	7-8-37	92	9-7-41	427,588
369	1,868	1,763	329	9-8-37	45	9-7-41	1,009,885
423	1,770	1,580	230	12-8-37	118	30-6-41	768,707
459	1,969	1,725	171	19-8-37	52	2-7-41	1,189,747
473	1,156	1,013	174	28-6-37	30	2-7-41	474,247
476	1,510	1,360	325	9-6-37	110	3-7-41	104,578
488	1,832	1,627	224	1-7-37	76	4-7-41	328,546
508	957	815	130	9-7-37	35	7-7-41	642,171

Production statistics of the Cabimas field are given in Table IV and data on the oil produced are assembled in Table V.

Gas-oil ratios are generally low and average 690 cubic feet per barrel. Average daily gas production during December, 1945, amounted to 12,250,000 cubic feet, of which 8,280,000 cubic feet were used in the field as fuel and also for gas-lift work after stripping off gasoline. A compressor plant, which in December, 1945, had a daily throughput of 6,400,000 cubic feet, supplies high pressure gas for the gas lift wells. The gasoline recovered from the compressor plant amounted to 65,400 barrels in 1945, or approximately 0.9 per cent of the total crude-oil production. It is blended with the crude oil for shipment to Curaçao.

Some years ago a gas-drive experiment was considered, but the scheme was not put into effect due to the experience of one of the Venezuelan Oil Concessions' competitors, the Lago (now Creole) Petroleum Corporation, who experimented for several years with repressuring in two areas in the lake opposite the Venezuelan Oil Concessions' wells, but finally abandoned it as being uneconomical due

to the early blowing through of gas. No further work of this nature is contemplated at present.

The original reservoir pressure of the field is unknown but is estimated to have been approximately 1,050 pounds per square inch at an average depth of

TABLE VII

ANALYSIS OF WATER FROM CABIMAS FIELD

Field:	Cabimas	Date sample collected:	July 7, 1944
Well No:	R-789	Date sample analyzed:	July 20, 1944
Depth:	1,236 feet	Method of sampling:	At well head

Color: Colorless, clear
Odor: Of petroleum acid soaps } after filtration
H_2S is not present
Free CO_2 is present and is 12 mgms. free CO_2 per liter
Naphthenic acids were not determined
Total alkalinity is equivalent to 1,648 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 378 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 378 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na'	1,739	75.61
Calcium	Ca''	54	2.70
Magnesium	Mg''	59	4.85
Positive sub-total			83.16
Chloride	Cl'	1,780	50.20
Sulphate	SO_4''	Nil	—
Carbonate	CO_3''	Nil	—
Hydrocarbonate	HCO_3''	2,011	32.96
Negative sub-total			83.16
Grand total		5,643	166.32

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	166 mgms.
Chloride salinity	100%
Primary salinity	60%
Primary alkalinity	31%
Secondary alkalinity	9%

Note: Sodium by difference
Remarks: Formations open to production: La Rosa, Santa Barbara and Icotea sands
Laboratory San Lorenzo

2,200 feet. A pressure-bomb survey was made for the first time in 1937, and was repeated in 1941. For comparative purposes the pressure decline observed in some wells is given in Table VI. Most wells ceased to flow long ago and are produced by artificial lifting methods (gas lift, central pumping powers, individual and twin pumps).

Water problems in the producing zones of this field are not of major importance, but care has to be taken in locating the water shut-off due to varying depths of the overlying water-bearing sands.

None of the water found so far in this field is suitable for domestic use. An analysis of water from the producing levels is given in Table VII.

The area of proved production of the Cabimas field is more than 5,000 hectares (approximately 12,350 acres). The wells were originally arranged on a grid of 400 meters triangular spacing (approximately 34-acre spacing) and a few locations are left for drilling on this grid. Many interspaced wells were drilled at 231 meters (approximately 11-acre spacing). There is still the possibility of opening the Upper Heavy Oil group, which has been produced lately, but in a few wells only. It is estimated that a fair number of productive wells could be drilled to this horizon. Additional small amounts of oil can probably also be produced from the Eocene just below the unconformity.

The oil produced in Cabimas is shipped by shallow-draft tankers to Curaçao for refining.

TIA JUANA FIELD

SITUATION AND DEVELOPMENT

The Tia Juana field of the Venezuelan Oil Concessions Limited is situated about half-way between Cabimas and Lagunillas near the shore of Lake Maracaibo on the swampy, alluvial plains of Rio Tamare and Rio Ule. Considerable drainage work was necessary to keep out the flood water of these rivers. Furthermore, some subsidence was observed in this field, which entailed the building of a sea-wall and pump stations to prevent flooding by the water of the lake. Maximum subsidence amounted to 0.96 meter (3 feet) from 1937 to 1943.

There are no oil seepages in the region of Tia Juana, and structural conditions are hidden by alluvium. The field was discovered by an extensive outstepping campaign conducted by the Lago Petroleum Corporation (now Creole Petroleum Corporation) in its lake concessions in 1928. The Venezuelan Oil Concessions Limited started exploitation in 1936. Development of the field was temporarily discontinued in July, 1940, but drilling was resumed in January, 1946.

The Venezuelan Oil Concessions field extends 6½ kilometers (4 miles) north and south along the lake shore, and about 2½ kilometers (1½ miles) eastward. Several outstep wells have been drilled still farther inland. The reservoir of the Tia Juana field stretches far under Lake Maracaibo, and is continuous with the reservoir of the Tia Juana and Punta Benitez fields which are exploited by the Mene Grande Oil Company and the Creole Petroleum Corporation. An offset agreement with these companies controls exploitation along the lake shore.

OIL AND GAS RESERVOIR

(Fig. 8)

Nearly all the oil and gas of the Venezuelan Oil Concessions' Tia Juana field is obtained from two productive levels at the base of the Lagunillas formation

which are separated by a thin shale break. The oil of both sands is characterized by the absence of light components. It varies in gravity from 16.0° to 10.5° A.P.I. (specific gravity 0.959–0.996).

The oil accumulation occurs on a fairly regular southwest-dipping monocline which is part of the wide Lagunillas-Cabimas synclinorium: The northern updip limit appears to be determined by a change from sand to shale facies in the Lagunillas sands and the southwestern (downdip) limit by edge water in these sands. Thus, the lower sand is water-logged in the southern part of the field, and only the upper sand is being produced in this area. The upper sand in turn is water-logged farther south. Along the strike, southeast and northwest, the oil accumulation has no clearly defined limits. It merges with the Punta Benitez and West Tia Juana accumulations under the lake, and it extends inland possibly joining the northwestern part of the Lagunillas reservoir, although the actual eastern limit of the Tia Juana accumulation is thought to be a major fault about 3 kilometers (1.8 miles) inland.

The total thickness of productive sand averages 150 feet in an area of 2,200 hectares (5,300 acres).

Three wells in the southern part of the field have produced small amounts of oil from the Eocene (lower Micaceous sandstone), but only one of them produces exclusively from the Eocene. This oil has a specific gravity of 0.917 (22.8° A.P.I.) and is thus much lighter than the Miocene oil.

DRILLING AND COMPLETION PRACTICE

Well depth ranges between 1,900 feet and 4,000 feet. Completion times are short—from 4 days to a maximum of 10 days per well. The wells drilled during the last drilling campaign previous to 1940, were completed with a $13\frac{3}{8}$-inch surface string cemented at about 250 feet, an $8\frac{5}{8}$-inch water string cemented above the oil zone, and a $6\frac{5}{8}$-inch 0.012-inch gauge screen liner hung with screen against the productive intervals and with blank casing against shale breaks. The $13\frac{3}{8}$-inch surface string was necessary because shallow gravel beds caused loss of circulation. It was omitted where such beds were absent.

Wells are washed into production. Franks portable rigs are used in Tia Juana and at least three wells are completed per string per month.

Little coring has been done in Tia Juana, since electrical logging provided satisfactory correlation (Fig. 4).

PRODUCTION

A total of 224 wells had been drilled in Tia Juana by the Venezuelan Oil Concessions Limited at the end of 1945. At that time 206 were producing (flowing 35, pumping 173). The remaining wells were closed. In December, 1945, the daily potential was 35,600 barrels and the field was producing to full capacity.

Average initial production rates were about 250 barrels per well before drilling was suspended in 1940. The decline rate of the field is estimated at 2 per cent per month. The field was partly closed in from 1942 to 1945 when the adverse

shipping situation and lack of demand for heavy oil prevented full exploitation. Production statistics can be found in Table VIII and the characteristics of the Tia Juana crude oil are given in Table IX.

Most of the crude oil produced in this field by the Venezuelan Oil Concessions has all the properties of a fuel oil and the gasoline recovery by distillation is negligible. The oil is so viscous that originally a larege number of wells were equipped with heaters to facilitate flowing production. As most of the wells are

TABLE VIII

PRODUCTION STATISTICS OF TIA JUANA FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1937	10,714,453
1938	16,054,041
1939	13,551,400
1940	8,840,316
1941	10,903,284
1942	4,695,098[1]
1943	249,193[1]
1944	1,153,850[1]
1945	6,156,772[1]
Total	72,318,407

PRODUCTION DURING DECEMBER, 1945

	Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*No. of Producing Wells*
Flowing	—	9,100	9,100	33
Pumping	—	26,500	26,500	173
Total	1,102,891	35,600	35,600	206

[1] Partly closed because of shipping situation.

now pumped, the oil is no longer heated at the individual wells, but is heated at the block stations and at the main storage tanks, before the crude is pumped to the tankers. The oil is still hot on arrival at the Island of Curaçao.

Gas-oil ratios are low, and average approximately 265 cubic feet per barrel of oil. The gas is very lean, the gasoline content being so small that it would not be economical to operate an absorption plant for its recovery. The quantity of gas is insufficient for gas-lifting purposes. The average daily amount of gas produced in December, 1945, was 9,250,000 cubic feet, of which 1,206,000 cubic feet per day were utilized for fuel purposes.

Water production has so far not been of much importance in this field, and has not caused any difficulty. However, as mentioned previously, there is definite evidence of edge water in the southern part of the field, and dehydration facilities may be required at a later date.

The oil of the Tia Juana field is probably produced by dissolved gas drive, perhaps to some extent by water drive. The first bottom-hole-pressure survey in the field was made in 1937, and such surveys have been repeated since. The

reservoir pressure in the northern part of this field was originally about 950 pounds per square inch at the base of the oil zone at a depth of 2,100 feet. In 1942 it had declined to approximately 600–800 pounds per square inch.

Potable water is found above the oil levels and is exploited by two water wells which take care of the domestic and field requirements of both the Creole Petroleum Corporation and the Venezuelan Oil Concessions Limited. As the water

TABLE IX

CHARACTERISTICS OF TIA JUANA CRUDE OIL

GENERAL	
Type	Asphaltic
Specific gravity range	0.965 to 0.992
A.P.I. gravity range	15.1° to 11.1°
CRUDE OIL TAKEN FROM MAIN STORAGE, APRIL 2, 1945	
Specific gravity 60/60°F.	0.977c
A.P.I. gravity	13.3°
Color by reflected light	Black
Color by transmitted light	Dark brown
Viscosity Engler at 30°C.	474°
Viscosity Engler at 50°C.	91.5°
Flash point	168°F.
Pour point test	40°F.
Paraffine wax	0.33%
Setting point of paraffine wax	57°C.
Sulphur	2.5%
Initial boiling point	158°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945	
Viscosity Redwood I at 100°F.	7,415 seconds
% gas oil required to reach 100% of oil of max. 3,500 secs. Redwood I at 100°F.	8.2%

contains impurities including fluoride, a filter and treating plant were erected jointly by the Venezuelan Oil Concessions and the Creole.

The proved area of the Tia Juana field is about 2,000 hectares (5,300 acres). Wells have been drilled on a triangular spacing grid of 400 meters (approximately 34-acre spacing) with interspaced wells on 231-meter spacing (approx. 11 acres) in those areas where good production can be obtained. Many wells remain to be drilled in proved and probable areas and development of the field was resumed in January, 1946.

All the oil produced in this field is shipped by shallow-draft tanker to Curaçao for refining. The tankers are loaded through a 15-inch welded submarine pipeline from a loading platform built on piles 1,200 yards from shore.

LAGUNILLAS FIELD

SITUATION AND DEVELOPMENT

The Lagunillas field of the Venezuelan Oil Concessions Limited is located about 70 kilometers (43 miles) southeast of Maracaibo on the shore of Lake

Maracaibo. It is situated partly in the Lagunillas swamp and partly on flat sandy plains bordering the swamp, which has been completely drained by the company.

Considerable subsidence has occurred in Lagunillas and has made necessary the construction of a sea-wall which protects the field against flooding by the lake. A system of drainage dikes and pump stations keeps the field dry. From 1926, when the first measurements were made, to 1944 a maximum subsidence of 3 meters (10 feet) has been observed.

The Venezuelan Oil Concessions commenced drilling its first exploration test El Mene de Lagunillas No. 1, situated 4 kms. (2.5 miles) east of the present producing area in May, 1925, and, although some oil was obtained, this well was abandoned as a commercial failure. In 1926 the Mene Grande Oil Company drilled Lago No. 1, the discovery well in Lagunillas, just off-shore in central Lagunillas and this exploration test resulted in prolific production. This new discovery led to a spirited offset drilling campaign of the Lago (now Creole) Petroleum Corporation, the Mene Grande Oil Company and the Venezuelan Oil Concessions in the competitive area along the lake shore. In the first years of development, drilling was very intensive and at one time the Venezuelan Oil Concessions had twelve strings operating in the field. Drilling was suspended in 1942.

To-day the proved area of the Venezuelan Oil Concessions' Lagunillas field extends 21 kimometers (13 miles) along the coast and has a maximum width of 5 kilometers (3 miles), covering approximately 7,660 hectares (18,900) acres. The same reservoir reaches far under Lake Maracaibo where it is exploited by the Mene Grande Oil Company and the Creole Petroleum Corporation. An offset spacing agreement with these companies regulates the density of producing wells along the lake shore.

OIL AND GAS RESERVOIR

(Fig. 9)

Most of the oil produced in the Lagunillas field is derived from the Miocene. Some Eocene sands are also open in a few wells but contribute little to the total production.

The following producing sands can be differentiated in the Miocene from top to bottom.

Tar sands	Gravity of oil 12.6°–10.6° A.P.I. (S.G. 0.986–0.996)
Heavy Oil zone	Gravity varies from 16° to 14.4° A.P.I. (S.G. 0.959–0.970)
Light Oil zone	Gravity ranges from 18.7° to 13° A.P.I. (S.G. 0.942–0.979)
La Rosa formation	In north part of field gravity ranges from 22.3° to 19° A.P.I. (S.G. 0.920–0.940); in south part it is 19°–12.4° A.P.I. (S.G. 0.940–0.983). Not present in central area of field

The Miocene sands with the exception of the Tar sands, are usually produced together. Heavy and Light Oil zones, in some areas together with the Upper Heavy Oil zone and the Lower Light Oil zone, are the main productive sands. The La Rosa formation is of less importance.

The productive sands in the Miocene are very loose and unconsolidated, and their effective porosity is estimated to be at least 25 per cent. The total thickness of the productive sands of the lower Lagunillas formation averages 80 feet in an area of more than 7,600 hectares.

There is evidence of water encroachment in the southern part of Lagunillas, but the field produces principally by dissolved gas drive. Water is also present in the northeastern and eastern parts of the field. In the northeastern area, the water has apparently migrated downdip across a former barrier fault due to reduction of pressure as a result of depletion of the oil reservoir.

DRILLING AND COMPLETION PRACTICE

At present there is no drilling in the Lagunillas field. At the end of the drilling campaign in 1942 a Franks portable rig was used. Wells were drilled as slim holes and completed with an $8\frac{5}{8}$-inch surface string at about 100 feet and $4\frac{1}{2}$-inch combination string cemented through ports above the zone which was to be produced. A 0.015-inch wire-wrapped screen was set against the sand sections and washed before the casing was cemented. Depths varied in general between 2,000 and 3,000 feet.

No cores were taken in recent wells and correlation was based entirely on Schlumberger logging (Fig. 9). In earlier wells coring was fairly extensive.

Completion time was short because wells were shallow and drilling was easy in the soft Miocene formations. In the more recent drilling operations wells were completed in an average of about 6 days.

PRODUCTION

A total of 827 wells had been drilled in the Lagunillas field by the Venezuelan Oil Concessions at the end of 1945. Of these, 679 were producing at the time (8 flowing, 671 pumping) and of the remainder, 62 were abandoned, the others were not producing for various reasons (repairs, high gas-oil ratio, *et cetera*).

Initial production rates were low when drilling was suspended and averaged about 100 barrels per day. The field as a whole has now a low rate of decline. Over the past few months it was about 1 per cent, after production had been restricted for some time (Table X).

The field had a potential of 72,000 barrels per day at the end of 1945 and produced to capacity. Production statistics are given in Table X and analytical data on the crude oil produced in Lagunillas are assembled in Table XI.

Gas-oil ratios are low and average 310 cubic feet of gas per barrel of oil. The average daily amount of gas produced during December, 1945, was 22,200,000 cubic feet, of which 5,250,000 cubic feet were used in the field as fuel and for other purposes. An absorption plant was installed early in the life of the field but operations were discontinued as the gas was found to be too poor for economical recovery of casing-head gasoline. Gas-lifting was abandoned when no wells remained in the field capable of supplying high-pressure gas.

No data are available about the original reservoir pressure of the Lagunillas field, but from estimates it appears to have been approximately 1,750 pounds per square inch at the base of the oil zone at an average depth of 2,500 feet. The first bottom-hole-pressure survey was made in 1937. These surveys have been continued since and indicate a marked pressure decline. Most of the wells were put on the pump long ago.

TABLE X

PRODUCTION STATISTICS OF LAGUNILLAS FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1926	319,306
1927	9,112,536
1928	19,254,047
1929	21,704,963
1930	18,666,699
1931	14,678,726
1932	14,555,240
1933	15,302,268
1934	21,829,647
1935	26,504,366
1936	29,171,397
1937	29,866,066
1938	30,242,075
1939	29,767,510
1940	23,476,441
1941	27,201,315
1942[1]	19,742,565
1943	24,536,932
1944	25,613,602
1945	26,946,668
Total	428,492,369

PRODUCTION DURING DECEMBER, 1945

	Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*No. of Producing Wells*
Flowing		1,900	1,900	8
Pumping		70,100	70,100	671
Total	2,249,295	72,000	72,000	679

[1] Partly closed because of shipping situation.

Water is present in the Light and Heavy Oil zones, and in certain sections of the field some of these levels have now become entirely water-bearing. The water produced with the oil forms a tight emulsion and can not easily be separated from the oil by settling. It has been necessary to install a large electrical dehydration plant consisting of 24 Petreco units, which have a rated total capacity of 28,800 barrels per day. In practice, it has proved possible to dehydrate an even larger quantity of wet crude, as can be seen from the operating figures for the month of December, 1945, when an average of 23 units were in operation.

	Crude Oil (Barrels)	*Average B.S.W.*[1] *(Percentage)*	*B.S.W. in Suspension (Barrels)*
Input	41,050	20.3	8,325
Output	32,725	1.86	623

[1] Bottom sediment and water.

Good potable water is found above the oil levels in the central part of the field,

TABLE XI

CHARACTERISTICS OF LAGUNILLAS CRUDE OIL

GENERAL		
Type	Asphaltic	
Specific gravity range	0.920 to 0.985	
A.P.I. gravity range	22.3° to 12.1°	
CRUDE OIL TAKEN FROM MAIN STORAGE APRIL 2, 1945		
	From Petreco Plant	*From Field*
Specific gravity 60/60°F.	0.9611	0.9624
A.P.I. gravity	15.7°	15.5°
Color by reflected light	Black	Black
Color by transmitted light	Dark brown	Dark brown
Viscosity Engler at 30°C.	111°	126°
Viscosity Engler at 50°C.	30.7°	31.4°
Flash point	64°F.	78°F.
Pour point test	Below 32°F.	Below 32°F.
Paraffine wax	0.33%	0.35%
Setting point of paraffine wax	56°C.	57°C.
Sulphur	2.1%	2.3%
Initial boiling point	75°C.	105°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945		
Yields by volume		
Gasoline	2.14%	
Gas oil	—	
Fuel oil	96.8%	
Properties of products		
Gasoline		
Specific gravity at 60°F.	0.715	
Distilling up to 100°C.	73%	
F.B.P. (A.S.T.M.)	149°C.	
Octane number (C.F.R. Motor method)	72	
Fuel oil		
Specific gravity at 60°F.	0.968	
Viscosity Redwood I at 100°F.	3,510 sec.	

and is being used for domestic purposes. An analysis of water from the oil-bearing formations is given in Table XII.

The field was originally arranged on a 400-meter triangular (approximately 34 acres) spacing grid. Later interspaced wells were drilled at 231 meters and a number of locations remain to be drilled chiefly on the interspaced grid, but on the whole the drilled-up stage has been reached.

During the last years, a few wells, in which the lower levels had been depleted,

TABLE XII

ANALYSIS OF WATER FROM LAGUNILLAS FIELD

Field:	Lagunillas	Date sample collected:	1-3-36
Well No.:	LS-197	Date sample analyzed:	17-3-36
Depth:	2,368 feet	Method of sampling:	Flow tank

Color: Very light brown, clear } after filtration
Odor: Of petroleum acids }
H_2S is not present
Free CO_2 is not present
Naphthenic acids were not determined
Total alkalinity is equivalent to 4,514 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 284 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 284 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil mgms. $CaCO_3$ per liter

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na′	2,003	87.09
Potassium	K″	—	—
Calcium	Ca″	10	0.50
Magnesium	Mg″	63	5.18
Positive sub-total			92.77
Chloride	Cl″	89	2.51
Sulphate	SO_4″	—	—
Carbonate	CO_3″	120	4.00
Hydrocarbonate	HCO_3″	5,263	86.26
Negative sub-total			92.77
Grand total		7,548	185.54

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	186 mgms.
Chloride salinity	100%
Primary alkalinity	91%
Primary salinity	3%
Secondary alkalinity	6%

Remarks: Sodium by difference
Formations open to production: Icotea formation, Light and Heavy Oil zone
Date: 17-3-36 Laboratory San Lorenzo

have been repaired and completed to exploit the Tar sands, which are situated in the upper part of the Lagunillas formation and contain very heavy oil. They represent a large reservoir which has so far hardly been touched.

All oil produced in the Lagunillas field is shipped by shallow-draft tanker to Curaçao for refining.

PUEBLO VIEJO FIELD

SITUATION AND DEVELOPMENT

The Pueblo Viejo field is situated on the Bolivar Coast between the Lagunillas and Bachaquero fields. It is located on a steeply folded Eocene anticline which is

buried under a thick cover of unconformable Miocene formations and the alluvial deposits of the Pueblo Viejo River. The anticline is a continuation of the East Lagunillas anticline exposed east of the Lagunillas field and was traced by geophysical methods (torsion balance and refraction shooting).

Exploration of the structure by drilling was carried out on three separate occasions: from April, 1937, to February, 1939; from February, 1940, to June, 1941; and from May, 1944, on. The first well drilled during the present campaign was completed producing 2,500 barrels of clean oil. Since then seven wells have been drilled by the Venezuelan Oil Concessions Limited and 4 wells by the Mene Grande Oil Company.

On land, all concessions covering the Pueblo Viejo anticline are held by the Venezuelan Oil Concessions Limited, but the structure continues presumably in a southern direction under Lake Maracaibo, where concessions belong to the Mene Grande Oil Company and to the Creole Petroleum Corporation.

Development of the Pueblo Viejo field is still in an exploratory stage, and little is known about stratigraphical and tectonic conditions. Still less can be said about accumulation, characteristics of production, and extent of the field.

Recent drilling took place in the swampy delta of the Pueblo Viejo River area near the lake shore, and required some drainage work. There are no oil or gas seepages in the area of the Pueblo Viejo field.

OIL AND GAS RESERVOIR

(Fig. 10)

At present, oil is produced in Pueblo Viejo from two sandstone bodies in the lower Micaceous sandstone. The upper one is 1,100 feet thick and is called the Pueblo Viejo Main sandstone. It is commonly found just below the Miocene unconformity. The specific gravity of the oil produced from the Main sandstone varies between 0.91 (24.0° A.P.I.) and 0.94 (19.0° A.P.I.). The second level is a thin sandstone about 750 feet deeper stratigraphically. It is called the LB-141 sandstone and contains oil of specific gravity 0.88 (29.3 A.P.I.) and 0.83 (38.2 A.P.I.).

Accumulation is controlled by folding and faulting of the Eocene in combination with the overlap of the Miocene. Production is probably more connected with fracturing and shattering of the sandstones than with primary porosity and permeability, which is very low as far as could be determined on the cores taken (Fig. 10).

At present, not much can be said about the extent of the field. It seems to consist of a number of fault blocks, in which favorably located holes are good wells while others a short distance away show water.

DRILLING PRACTICE AND COMPLETION

Wells in Pueblo Viejo are drilled with steam rigs. The depth of the wells varies between 2,000 and 4,000 feet. Drilling is rapid in the Miocene, slow in the

hard sandstones of the Eocene. Surface casing ($10\frac{3}{4}$-inch) is usually cemented at depths of 400 to 800 feet and $5\frac{5}{8}$-inch or 7-inch casing is set at the bottom of the well or below the oil levels, but completion practice is in an experimental state and varies for each well as conditions change rapidly; it consists mainly of cementing opposite the prospective sandstones and bullet-perforating the casing. Open-hole completion was also tried recently. Completion time averages 2–3 months, as it includes much testing. Coring was fairly intensive in the first well of the recent drilling campaign and served to study fluid content, composition, and physical characteristics of the formations. Schlumberger logs are run and deviation and self-potential dipmeter surveys made.

The Venezuelan Oil Concessions Limited had three rigs operating in the Pueblo Viejo field at the end of December, 1945.

TABLE XIII

PRODUCTION STATISTICS OF PUEBLO VIEJO FIELD

ANNUAL PRODUCTION IN BARRELS			
Year	*Barrels*		
1940	101,920		
1941	120,495		
1942	—		
1943	—		
1944	81,120		
1945	1,215,943		
Total	1,519,478		
PRODUCTION DURING DECEMBER, 1945			
Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*Number of Producing Wells*
108,619	3,500	3,550	6

PRODUCTION

A total of 15 wells had been drilled on the Pueblo Viejo structure by the Venezuelan Oil Concessions Limited at the end of 1945. Six wells were producing at that time (5 flowing, 1 pumping) two were closed because of outlying position, two were abandoned, and the remaining wells were awaiting repairs or were being worked on.

Initial production can be high, but is not predictable. Production records of the Pueblo Viejo field are shown in Table XIII and the characteristics of the Pueblo Viejo oil are given in Table XIV.

Gas-oil ratios range from 110 to 930 cubic feet per barrel for the Pueblo Viejo Main sandstone, but are considerably higher for the lower sand. Gas production during December, 1945, was 172,000 cubic feet per day, of which the greater part was used in operations.

Water production is a serious problem and many water-bearing sands have to

be shut off. An analysis of water from the Pueblo Viejo Main sandstone is given in Table XV. No pressure-bomb survey has been made so far, but casing-head pressures vary from 230 to 570 pounds per square inch. Well spacing is irregular

TABLE XIV

CHARACTERISTICS OF PUEBLO VIEJO CRUDE OIL

GENERAL		
Type	Asphaltic	
	Bachaquero Main Storage	*Well LB-141 3,728–3,803 Feet*
CRUDE OIL ANALYSIS, APRIL 2, 1945		
Specific gravity 60/60°F.	0.9326	0.836
A.P.I. gravity	20.2°	38.2°
Color by reflected light	Black	
Color by transmitted light	Dark brown	
Viscosity Engler at 30°C.	9.08°	
Viscosity Engler at 50°C.	3.59°	
Flash point	92°F.	
Pour point test	Below 32°F.	Below 48°F.
Paraffine wax	0.1%	
Setting point of paraffine wax	56°C.	
Sulphur	1.04%	0.31%
Initial boiling point	127°C.	75°
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945		
Yields by volume		
Gasoline	2.78%	
Gas oil	27.90%	
Fuel oil	68.32%	
PROPERTIES OF PRODUCTS		
Gasoline		
Specific gravity at 60°F.	0.758	
Distilling up to 100° C. (A.S.T.M.)	15%	
F.B.P. (A.S.T.M.)	176°C.	
Octane number (C.F.R. Motor method)	72	
Gas oil		
Specific gravity at 60°F.	0.868	
Distilling up to 300°C. (A.S.T.M.)	77%	
Sulphur content	0.36%	
Diesel index	41.6	
Fuel oil		
Specific gravity at 60°F.	0.973	
Viscosity Redwood I at 100°F.	3,560 sec.	

as it has to conform with the complicated structural conditions. The oil produced in the field is pumped to Bachaquero and shipped from there to Curaçao for refining.

BACHAQUERO FIELD

SITUATION AND DEVELOPMENT

Bachaquero is the southernmost of the Bolivar Coast fields. It is situated on a flat, swampy alluvial plain along the shore of the Lake Maracaibo. Much drainage

work was required in order to make operations possible. A dredged channel extends 11.5 km. (7 miles) along the lake shore, and a ditch and bank 20.2 km. (13.5 miles) long protect the field against inland flooding. A system of ditches within the banked area is connected with the main drainage channel.

There are no seepages or outcrops in the region, and the field was discovered

TABLE XV

ANALYSIS OF WATER FROM PUEBLO VIEJO MAIN SANDSTONE

Field:	Pueblo Viejo	Date sample collected:	July 13, 1944
Well No.:	LB-124	Date sample analyzed:	July 19, 1944
Depth:	2,274 feet	Method of sampling:	At well head

Color: Colorless, clear } after filtration
Odor: Of petroleum }
H_2S is not present
Free CO_2 is present and is 23 mgms. free CO_2 per liter
Naphthenic acids were not determined
Total alkalinity is equivalent to 5,126 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 329 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 329 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na′	4,608	200.36
Calcium	Ca″	36	1.80
Magnesium	Mg″	58	4.77
Positive sub-total			206.93
Chloride	Cl′	3,700	104.34
Sulphate	SO_4″	5	0.10
Carbonate	CO_3″	—	—
Hydrocarbonate	HCO_3″	6,253	102.49
Negative sub-total			206.93
Grand total		14,660	413.86

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	414
Chloride salinity	100%
Primary salinity	51%
Primary alkalinity	46%
Secondary alkalinity	3%

Remarks: Sodium by difference
Interval open: 2,190–2,210 feet
Date: July 20, 1944 Laboratory San Lorenzo

in 1930 by the Mene Grande Oil Company outstepping from known productive areas. The first well, Lagunita 1, blew out from the Bachaquero sands when the plugs were drilled out, and flowed at an estimated rate of 4,500 barrels a day

through the drill pipe. The Venezuelan Oil Concessions Limited did not start operations until 1936. The first well had an initial daily production of 1,000 barrels of oil of specific gravity 0.974 (13.7° A.P.I.) on ½-inch bean. Active exploitation of the field began in 1938, but development was interrupted from 1939 to 1941 and again in 1942 because of the war and was not resumed until January, 1945.

To-day the proved area of the Bachaquero field of the Venezuelan Oil Concessions Limited extends 6.5 km. (4 miles) north and south with a maximum width of 7 km. (4.3 miles). The limits of the field have not been determined and there is reason to believe that it will eventually be greatly enlarged. The reservoir of the field extends under Lake Maracaibo and is exploited there by the Mene Grande Oil Company and the Creole Petroleum Company. An offset agreement regulates the drilling along the lake shore.

OIL AND GAS RESERVOIR

(Fig. 11)

Oil is produced in the Bachaquero field from the Bachaquero sands and the La Rosa formation. The latter has been recognized so far only in the central coastal area. The total thickenss of sand in the productive interval varies from about 100 to 200 feet, according to local development. An effective porosity of 25 per cent is commonly assumed.

Some oil-impregnated sandstone has been found in the Eocene, but can not yet be classified as a commercially productive level.

The Bachaquero sands are subdivided into Heavy and Light Oil zones. The oil of the Heavy Oil zone has a gravity ranging from 13.7° to 11.5° A.P.I. (S. G. 0.975–0.990). In the Light Oil zone the gravity ranges from 17.9° to 14° A.P.I. (S. G. 0.947–0.972). The La Rosa oil has a gravity of approximately 17° A.P.I. (S.G . 0.95). These sands are usually produced together.

Up to the present there is no evidence of water-drive conditions but it is too early for a final opinion as the field has been producing for a relatively short period only. It seems that the field produces by dissolved gas drive. No water is so far produced from the oil levels in the Bachaquero field.

The limits of the productive area may be controlled by pinching-out of the productive formations and changes of porosity and permeability.

DRILLING AND COMPLETION PRACTICE

The present drilling campaign was started in January, 1945, and wells are drilled at an average of two per string per month. They are of medium depth, averaging from 4,000 to 5,000 feet and are completed with a $13\frac{3}{8}$-inch surface string cemented at 100 feet, an $8\frac{5}{8}$-inch water string cemented above the oil zone, and a $6\frac{5}{8}$-inch wire -wrapped (0.012-inch gauge) screen liner equipped with Brown liner hanger and wash shoe hung opposite the productive formation.

Considerable sand trouble has been experienced, because the sands are very

fine-grained and unconsolidated. Wells are produced on small beans in order to maintain an undisturbed sand pack outside the screen.

Little coring has been done in Bachaquero as electrical logging provides a satisfactory method for correlation of the formations and determination of the oil-bearing sands.

PRODUCTION

A total of 128 wells had been drilled by the Venezuelan Oil Concessions Limited at the end of 1945. Of these, 115 were producing (flowing 112, pumping 3), 1 was abandoned, and the remaining wells were closed in or being worked on.

TABLE XVI

PRODUCTION STATISTICS OF BACHAQUERO FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1936	5,600
1937	20,500
1938	929,056
1939	3,382,620
1940	1,637,100
1941	761,320[1]
1942	2,693,436
1943	2,823,770
1944	5,666,744
1945	10,990,626
Total	28,910,772

PRODUCTION DURING DECEMBER, 1945

Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*Number of Producing Wells*
994,996	32,100	32,250	115

[1] Low, due to shipping difficulties.

Production statistics are shown in Table XVI and the characteristics of the Bachaquero crude oil are given in Table XVII.

Initial production of 1,000–2,000 barrels per day could be obtained on large beans, but on $\frac{5}{8}$-inch beans it varies from 300 to 600 barrels per day. The field is still in the early stages of development, and locations in considerable number, even in the proved area, remain to be drilled. The decline rate in this field has been fairly large, the present estimate being 5 per cent. At the end of 1945 the Venezuelan Oil Concessions had a potential production of 32,500 barrels per day in Bachaquero and the field was being produced to capacity.

Gas-oil ratios are low and average 550 cubic feet per barrel of oil for the whole field. The gasoline content of this gas is not considered sufficient to warrant a plant for its recovery. The average daily amount of gas produced during December, 1945, was 2,825,000 cubic feet, of which 126,000 cubic feet per day were used as fuel in the field.

The first bottom-hole-pressure survey was made in the Bachaquero field in 1939–1940, at which time only 39 wells had been drilled. From this survey it is estimated that the original reservoir pressure was 1,800 pounds at the top of the Eocene at an average depth of 3,600 feet. The surveys have been continued and show a marked decline of pressure centered around the two producing areas.

TABLE XVII

CHARACTERISTICS OF BACHAQUERO CRUDE OIL

GENERAL	
Type	Asphaltic
Specific gravity range	0.944 to 0.980
A.P.I. gravity range	18.4° to 11.7°
CRUDE OIL TAKEN FROM MAIN STORAGE, APRIL 2, 1945	
Specific gravity 60/60°F.	0.9704
A.P.I. gravity	14.3
Color by reflected light	Black
Color by transmitted light	Dark brown
Viscosity Engler at 30°C.	159°
Viscosity Engler at 50°C.	37.0°
Flash point	84°F.
Pour point test	Below 32°F.
Paraffine wax	0.21%
Setting point of paraffine wax	58°C.
Sulphur	2.5%
Initial boiling point	88°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945	
Yields by volume	
Gasoline	0.88%
Gas oil	—
Fuel oil	98.12%
Gasoline	
Specific gravity at 60°F.	0.702
Distilling up to 100°C.	94½%
F.B.P. (A.S.T.M.)	124°C.
Octane number (C.F.R. Motor method)	77
Fuel oil	
Specific gravity at 60°F.	0.974
Viscosity Redwood I at 100°F.	3,450 sec.

The proved area of the field is 6,000 hectares (14,800 acres) and wells have been drilled on a triangular spacing grid of 231 meters (approximately 11 acres), though, during 1945, drilling was confined to 400 meters (approximately 34 acres) spacing to conform with regulations of the Petroleum Administration for War. The limits of the field have not yet been defined and further outstep drilling will be required.

In the upper part of the Miocene well above the oil zones a series of water-bearing sands is present 2,000–2,600 feet below lake level, averaging about 400

feet in thickness. Three wells have been drilled in the central area to exploit this water for domestic purposes.

All the oil produced in Bachaquero is shipped by shallow-draft tanker to Curaçao for refining.

Part III. Mene Grande Field

SITUATION AND DEVELOPMENT

The Mene Grande field of the Caribbean Petroleum Company is situated on the eastern side of Lake Maracaibo, 19 km. (12 miles) inland from the lake shore. It is located in the district of Sucre, State of Zulia, approximately 120 kilometers (73 miles) southeast of Maracaibo (Fig. 1).

The field is located on the south plunge of the Misoa anticline, which forms high mountains north of Mene Grande. The earlier wells were drilled in the low hills of the plunge but subsequent development extended southward into the alluvial plains which surround the Misoa anticline, and which are swampy along the San Pedro River and farther south. Particularly in the recently developed El Veleto area in the southern part of the field, dikes have had to be built to control flood waters. The northern part of the field, in which the camp and installations are located is in hilly, broken country, or open savannas. The elevations of the wells vary from 30 to 220 feet throughout the field.

The productive Miocene formations are exposed just north of the field and a great number of active seepages occur on the plunge of the Misoa anticline along the outcrops of the productive Miocene. Farther north, along the west flank, there are large asphalt deposits. The area is favorable for photogeological studies but these came too late to influence the development of the field.

The presence of large seepages attracted attention to Mene Grande and geological investigations were made at an early date. Drilling started in January, 1914, with cable tools and Miocene oil was produced from the first wells. A pipeline to San Lorenzo on the shore of Lake Maracaibo was completed in January, 1917, and the construction of a refinery at this locality began during the same year. Drilling was slow during the first 8 years, but, by the end of 1925, fifty wells had been completed. Rotary drilling was then introduced and completions were more rapid.

An important event in the history of the Mene Grande field was the discovery of light oil in the Paují formation of the Eocene at the end of 1925. Later, prolific production was also obtained in the Misoa-Trujillo formation of the Eocene. Subsequently, many old wells were deepened to the Eocene, and a considerable number of new wells were drilled for this objective.

An extension of the Eocene accumulations was discovered in 1940 in the so-called El Veleto area with the completion of well MG-407. El Veleto is situated considerably down the plunge, and drilling in this area was based on the results of a seismic survey.

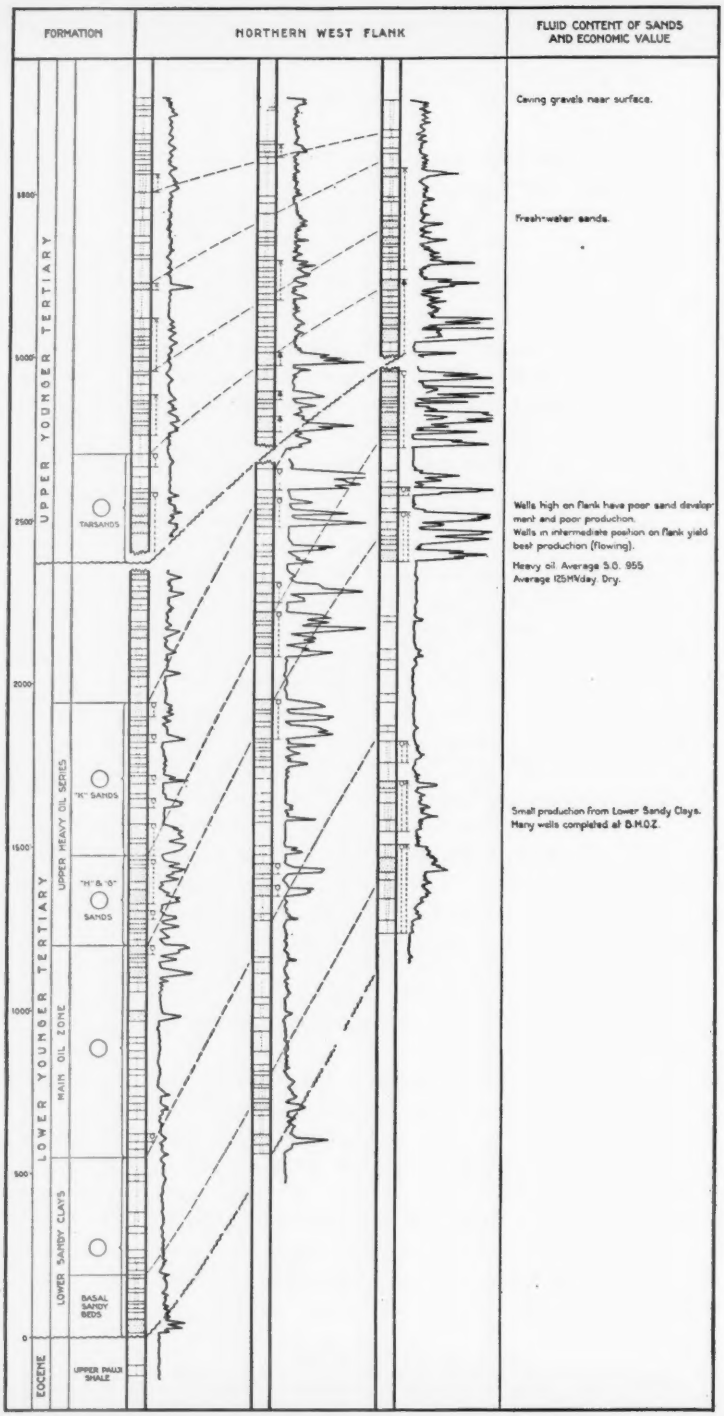


FIG. 12.—Type sections of Miocene in northern west flank of Mene Grande field. Note unconformity between upper and lower Younger Tertiary. Mene Grande formation is cut out by Miocene transgression. Circles indicate oil accumulations.

Early light-oil wells were prolific, but water soon made its appearance in large quantities and the Eocene production of Mene Grande has not had, on a total production basis, the importance which was originally anticipated.

The productive area of the field extends approximately 11 kilometers (6.7 miles) north and south and 5 kilometers (3 miles) and east west. All the concessions on which the field is situated are owned by the Caribbean Petroleum Company.

STRATIGRAPHY[14]

(Figs. 12 and 13)

As in the Bolivar Coast fields, the beds encountered in the Mene Grande field belong to the Eocene and the Miocene. The Miocene transgresses over several Eocene formations with a pronounced unconformity.

EOCENE

The Eocene of the Mene Grande field and surrounding area is subdivided, from top to bottom, into three formations: Mene Grande, Paují, and Misoa-Trujillo.

The subdivision is based partly on lithology and partly on faunal content. All three formations are believed to be of middle Eocene in age.

Misoa-Trujillo formation.—Only the uppermost part of the Misoa-Trujillo formation is known in the Mene Grande field, where it is subdivided from top to bottom into: the Transition zone, the Main sandstone, and the Lower sandstones and shales.

The Transition zone represents lithologically and faunally the transition from the fossiliferous Paují shales to the barren sandstones of the Misoa-Trujillo. Its top is very well defined as the first hard sandstone below the Paují, and appears on the electrical log as a sharp peak. The Transition zone is 200-350 feet thick and consists of numerous shale bodies interbedded with sandstones. Four different sandstone groups are recognized as can be seen in Figure 13.

The Main sandstone is composed mainly of hard, non-bedded sandstones with a few thin shale intercalations. Here six sandstone groups are recognized, the total thickness amounting to 500 feet.

The Lower sandstones and shales are a group of interbedded sandstones and sandy shales. About 600 feet have been perforated on the Main Light Oil uplift.

Paují formation.—The Paují formation consists of approximately 2,000 feet of black or dark gray, hard shales with many calcareous concretions. It is difficult to determine the exact thickness of the formation because of the Miocene unconformity and structural complications.

On the basis of microfaunal differences the Paují formation is subdivided into upper, middle, and lower Paují. The middle Paují is especially important because it contains a thin group of sandstones about 850 feet above the top of the Misoa-Trujillo formation. This so-called middle Paují sandstone decreases from

[14] G. E. Tash, "Stratigraphy and Palaeontology of Mene Grande and Vicinity," *Bol. Geologia y Mineria*, Vol. 1, Nos. 2–4. Caracas (1938).

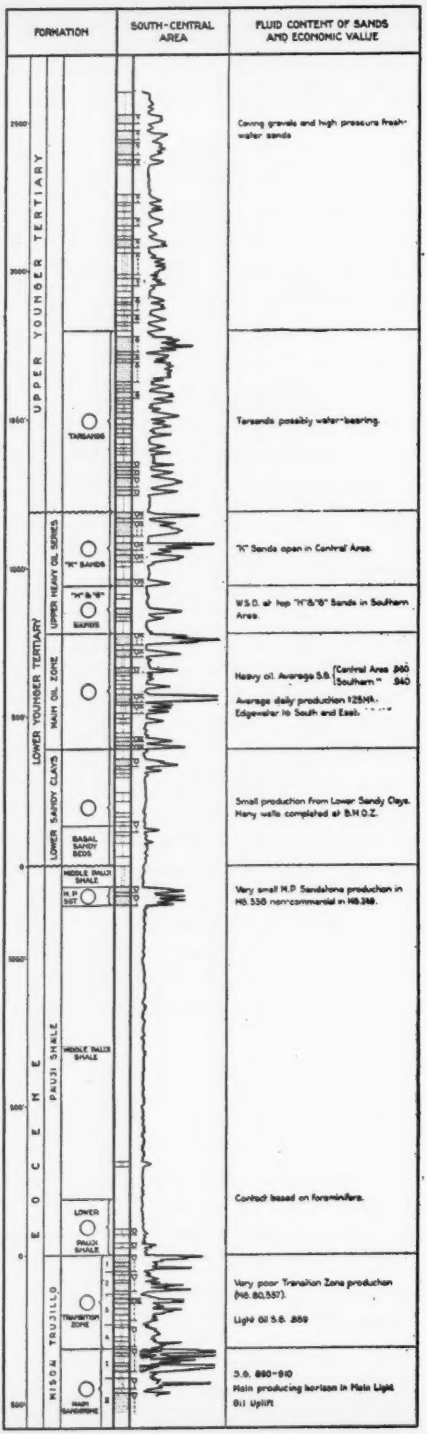

FORMATION
SOUTH-CENTRAL AREA
FLUID CONTENT OF SANDS AND ECONOMIC VALUE
UPPER YOUNGER TERTIARY
LOWER YOUNGER TERTIARY
UPPER HEAVY OIL SERIES
MAIN OIL ZONE
LOWER SANDY CLAYS
MIOCENE
PAUJI SHALE
MISOA TRUJILLO
TARSANDS
"K" SANDS
"H" & "G" SANDS
BASAL SANDY BEDS
MIDDLE PAUJI SHALE
H.P. SST
LOWER PAUJI SHALE
TRANSITION ZONE
MAIN SANDSTONE
Caving gravels and high pressure fresh-water sands
Tarsands possibly water-bearing.
"K" Sands open in Central Area.
W.S.O. at top "H" & "G" Sands in Southern Area.
Heavy oil. Average S.G. Central Area .960 Southern " .940
Average daily production 125 M³. Edgewater to South and East.
Small production from Lower Sandy Clays. Many wells completed at B.H.O.Z.
Very small H.P. Sandstone production in Hb.330 non-commercial in Hb.348.
Contact based on foraminifera.
Very poor Transition Zone production (Hb.80,557).
Light Oil S.G. .859
S.G. 880-910
Main producing horizon in Main Light Oil Uplift

FIG. 13.—Type section of Eocene and Miocene in south-central part of Mene Grande field. Mene Grande formation and upper Paují are cut out by unconformity. Circles indicate oil accumulation.

a maximum thickness of 150 feet in the southernmost part of the field to about 30 feet in the center of the field, where it is cut out by the Miocene transgression. Farther north this sandstone is absent even in complete sections of the Paují formation. In the south, where it is best developed, it is composed of several sandstones with intercalated sandy shales while in the north it is represented by a single sandstone body or by sandy shales. The lower Paují is composed of approximately 300 feet of somewhat sandy shales, which contain some megafossils in addition to a poor microfauna. The approximate thickness of the middle Paují is 750 feet, of the upper Paují 800–900 feet.

Mene Grande formation.—The Mene Grande formation is the uppermost Eocene formation known in Mene Grande and is cut out by the Miocene unconformity in large parts of the field. The lower part of the formation consists of dark gray shales which closely resemble those of the Paují formation but can be differentiated from them by their faunal content. The upper part is sandy and includes many thin, calcareous sandstone beds. They contain an orbitoid fauna, which is probably of upper middle Eocene (Claiborne) age. The total thickness of the formation can not be measured because of the Miocene unconformity. Thicknesses observed in the field range from almost nothing to 120 feet, but east of the field, in the Raya syncline, the total thickness is estimated to be about 2,150 feet.

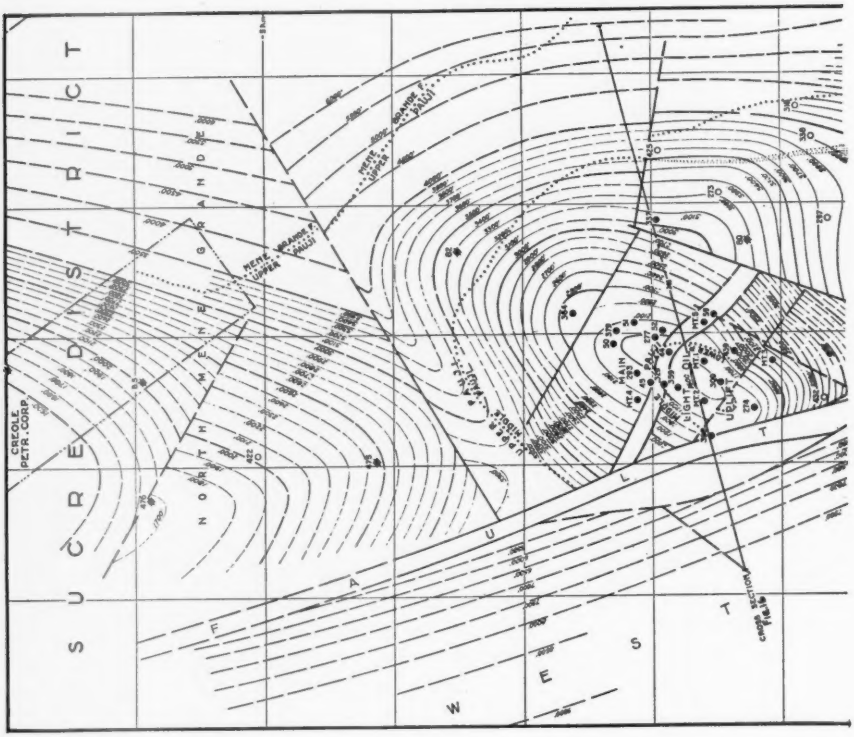
MIOCENE

The sandy clays and sands which transgress over the Eocene have been assigned to the Miocene for the purpose of this paper. This is somewhat arbitrary, as no fossils have been found which allow an age determination. However, these beds occur in the same position as the Miocene in the Bolivar Coast fields, namely, transgressive on Eocene and strongly folded during the Andean orogeny. No direct correlation with the Bachaquero field exists, but the Miocene of Mene Grande probably corresponds with the upper part of the Lagunillas and the lower part of the La Puerta formation.

In field terminology these beds are called Younger Tertiary, for lack of a better defined name, and are subdivided into upper and lower Younger Tertiary.[15]

Miocene unconformity.—The lower Younger Tertiary is transgressive on the Eocene. On the highest part of the structure the unconformity reaches the lower Paují formation, about 200 feet above the top of the Misoa-Trujillo formation. On the flanks of the uplift, the lower Younger Tertiary rests on higher beds of the Paují formation and, in some parts of the east flank and the Veleto area, on the Mene Grande formation. It has been possible to map the Eocene formations on the surface of the unconformity (Fig 14). The intersection of the middle Paují sandstone with the unconformity, which has been determined on

[15] Field geologists of the Caribbean Petroleum Company call any undifferentiated beds younger than Oligocene "Younger Tertiary." We have tried to avoid the term but are not in favor of the term Maracaibo group proposed by G. E. Tash (*op. cit.*), as that should be restricted to the mottled clay series exposed in the Maracaibo and Mara districts.


SUCRE DISTRICT
CRICOLE PETR. CORP.
MESA LOWER
MESA M. SAND
MESA UPPER
MESA M. SAND
PETIT GRANDE F. SAND
PETIT GRANDE F. SAND
NORTHWEST
FAULT
SOUTHEAST
UPPER
LOWER
MAIN
PETIT GRANDE
CROSS SECTION

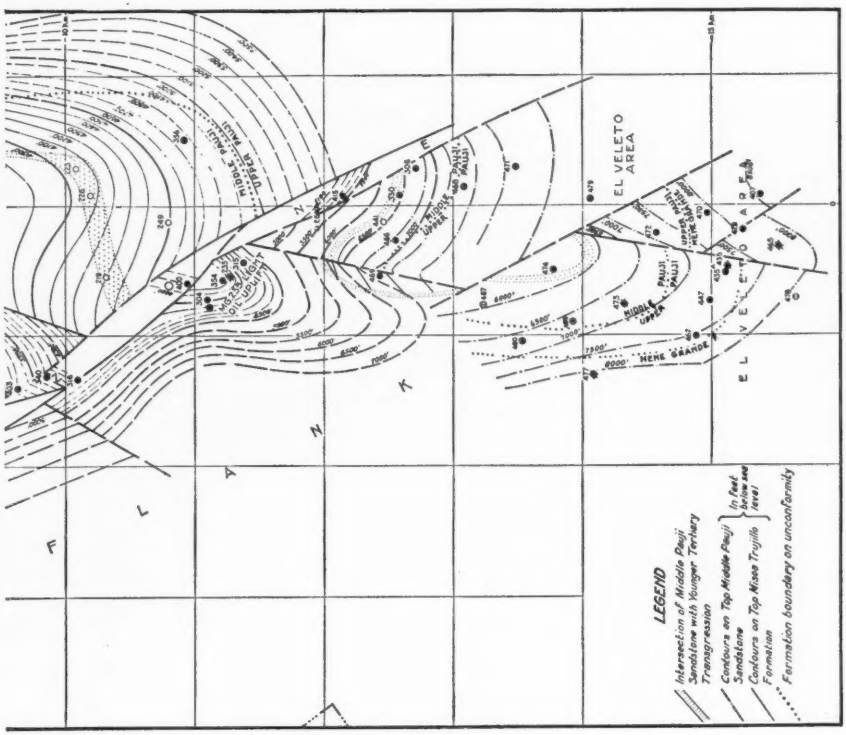
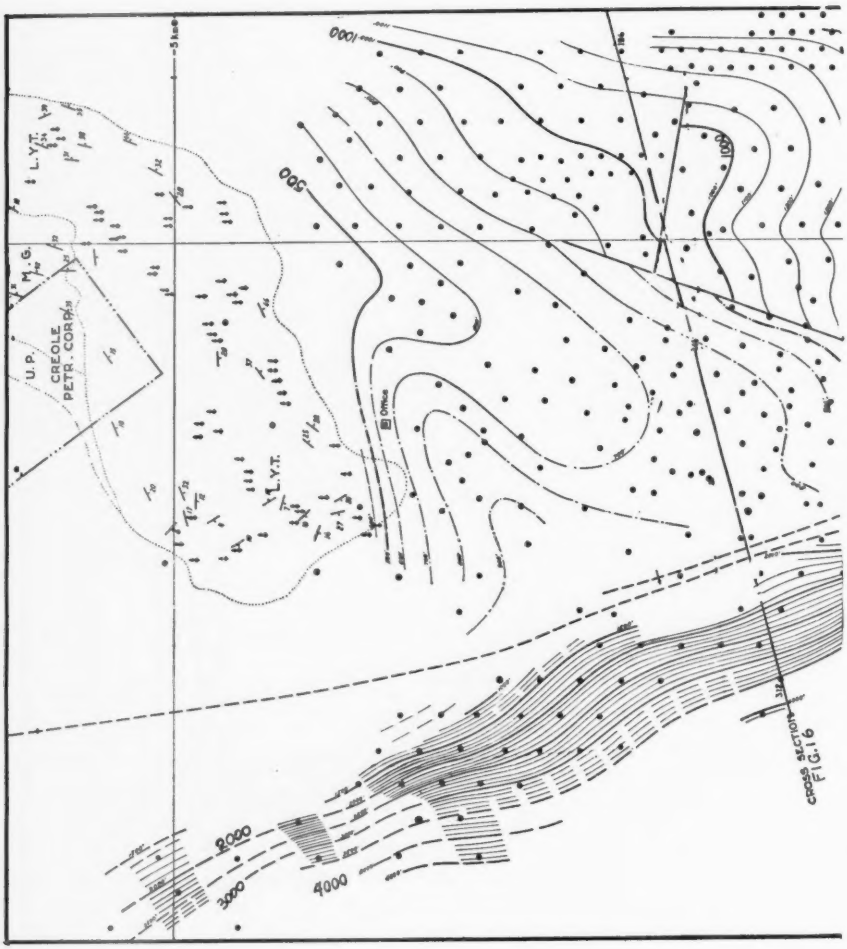

EL VELETO AREA
MENE GRANDE
LEGEND
Intersection of Middle Pauji Sandstone with Younger Tertiary Transgression
Contours on Top Middle Pauji Sandstone
Contours on Top Misoa Trujillo Formation
In feet below sea level
Formation boundary on unconformity

FIG. 14.—Structural contour map of Eocene in Mene Grande field. Note horizontal displacement along Main fault zone between Main Light Oil uplift and Mg. 235 uplift. Solid circles: Eocene producers. Open circles: Miocene wells bottomed in Eocene. Scale, 1:50,000. Map is correctly oriented: north at top; south at bottom.


L.Y.T.
M.G.
U.P.
CREOLE
PETR. CORP.
L.Y.T.
Office
500
1000
8000
3000
4000
CROSS SECTION
FIG. 16

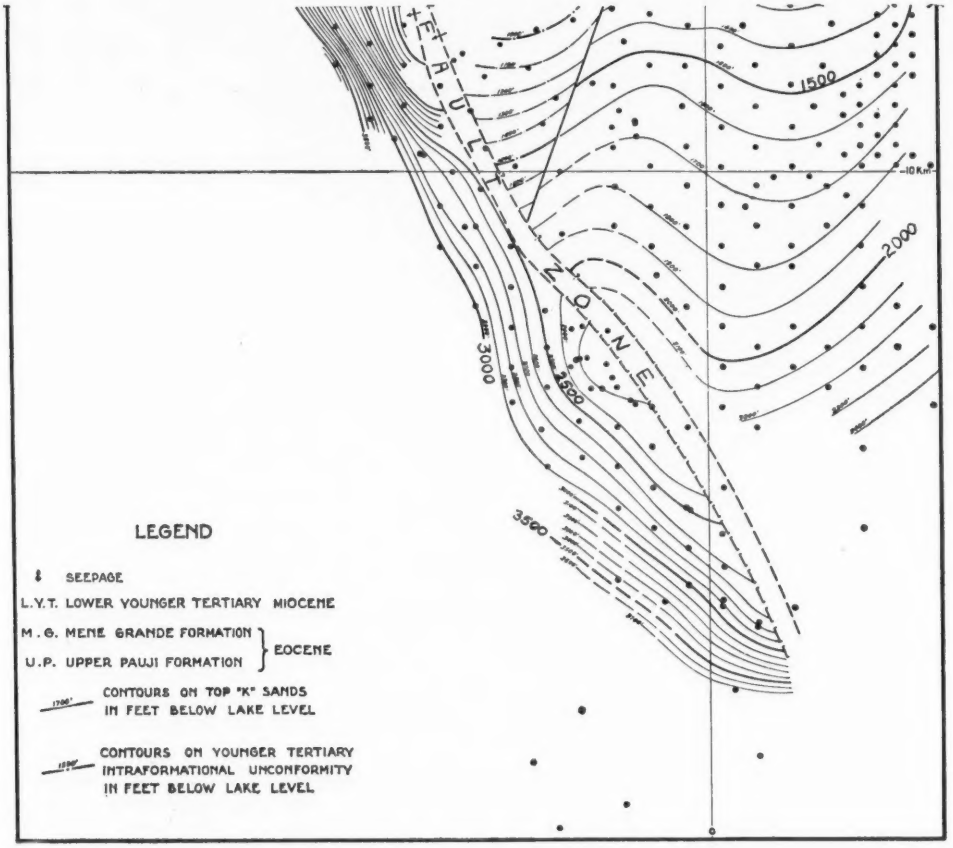


FIG. 15.—Structural contour map of Miocene in Mene Grande field. Outcrops and seepages just north of producing area are also shown. One inch = 1 kilometer. Map is correctly oriented: north at top; south at bottom.

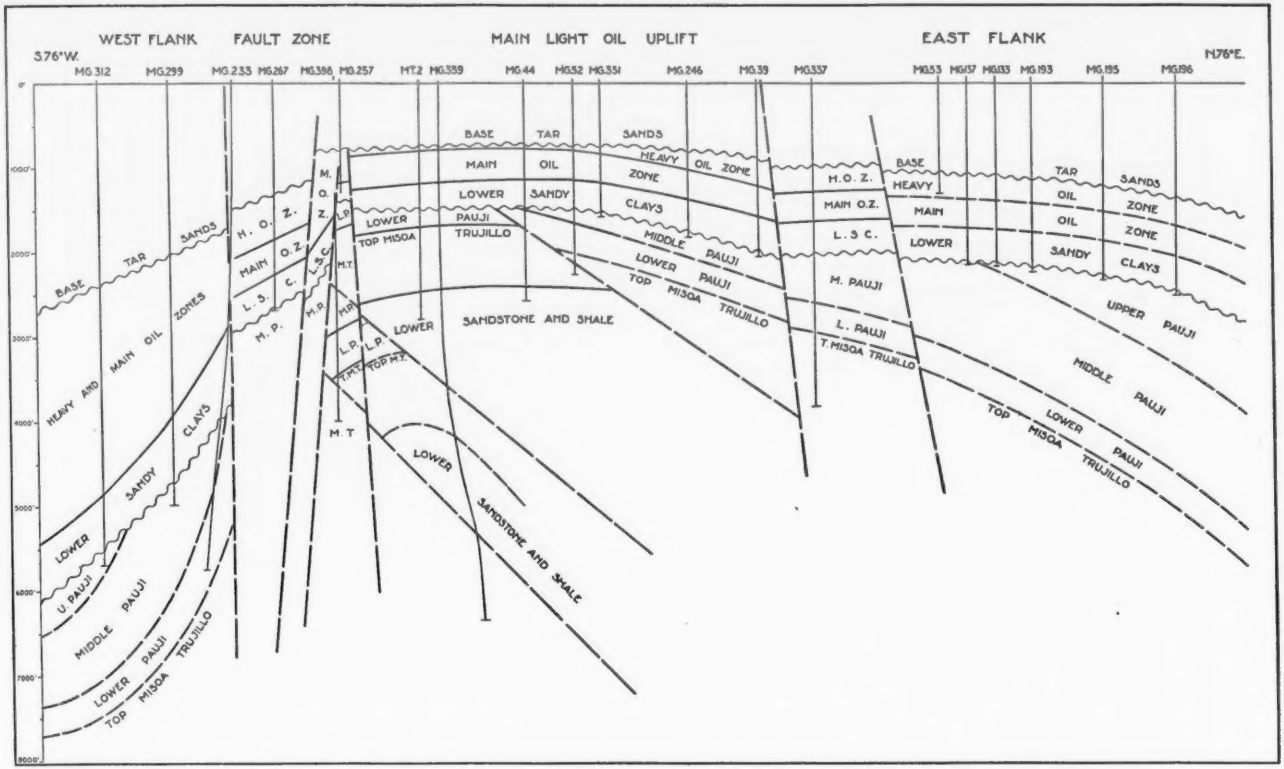


FIG. 16.—Cross section through Mene Grande field, according to B. H. Mull. Vertical and horizontal scales equal (see left margin).

the plunge of the structure is of great importance for the development of the middle Paují production.

Subsurface studies show clearly that some tectonic elements of the Mene Grande field, for example, the Main Light Oil uplift, already existed in pre-Miocene time. The magnitude of the pre-Miocene tectonic movements can be judged from the fact that, within the limits of the field, the Younger Tertiary transgresses over an Eocene interval of approximately 2,000 feet. The uplifts resulting from these movements had been levelled out by erosion prior to the transgression.

Lower Younger Tertiary.—The lower Younger Tertiary is subdivided into lower Sandy clays, Main Oil zone and Upper Heavy Oil series, the last being in turn split into several sands. All these beds are exposed on the east flank and on the plunge of the Misoa anticline. They consist mainly of white to yellow, poorly consolidated sands interbedded with mottled sandy clays. Mottled clays predominate in the lower sandy clays, just above a series of white basal sands.

On the west flank, higher strata come in above the upper Heavy Oil series and increase in thickness downdip (Fig. 12).

Upper Younger Tertiary.—The upper Younger Tertiary rests with an unconformity on the lower Younger Tertiary. This can be well observed on the west flank where at least 500 feet of the section are cut out below the transgression. Tectonic movements caused an uplift in the Mene Grande area during Miocene time, sedimentation was interrupted and considerable erosion took place before the area was covered by younger deposits. It is probable that the unconformity is restricted to the area of the Misoa anticline, and that away from the uplift, in the deeper parts of the Maracaibo Basin west of Mene Grande, sedimentation was continouus.

The basal sands of the upper Younger Tertiary are called Tar sands, because of the heavy tarry oil contained in them. Higher sands are fresh-water-bearing. In general the upper Younger Tertiary consists of loose sands intercalcated with mottled sandy clays and is even less consolidated than the lower Younger Tertiary.

STRUCTURE

(Figs. 14–16)

The Mene Grande field is situated on the south-plunging asymmetric Misoa anticline which is bordered on the east by the Raya syncline, on the west by the alluvial plain covering the wide Machango-Sibaragua synclinorium (see also under Bolivar Coast fields), which separates Mene Grande from Bachaquero. These major structural units have a strong morphological expression which closely follows the tectonic development.

The structure of the field itself can be described as an anticline with a steep, strongly faulted west flank (50°–70°), and a gentle east flank (10°–30°) which plunges south with an over-all dip of approximately 10°. The trend of the anti-

cline is north and south. However, in addition to this main direction, a north-northeast trend is plainly visible in the so-called Main Light Oil uplift and the MG–235 Light Oil uplift. These two structural units represent a small dome about 2 km. (1.2 miles) long, which was already present long before the Miocene was deposited. This can be deduced from the fact that pre-Miocene erosion was strongest on the crestal zone of the dome, where it reached the lower Paují formation. During later stages of structural development the dome was involved in the post-Miocene Misoa anticline.

There is much evidence of faulting in the Mene Grande field. Of greatest importance from an exploitation point of view is the big fault zone which follows the west flank in the northern part of the field and cuts across the Main Light Oil uplift. It strikes north-northwest and has been mapped over a length of 8 km. (5 miles). The tectonics of this fault zone are not yet understood in detail, and very little is known about its hade. It is thought, however, that a shear movement took place by which the eastern block was shifted 2.5 km. (1.5 miles) northward with respect to the western block. This can be seen in the displacement between Main Light Oil uplift and MG-235 Light Oil uplift. Whether a thrust movement is connected with the fault zone is not ascertained but is quite possible. It seems that the Eocene is more affected by the fault zone than the Miocene, and it can thus be assumed that the fault zone existed already in pre-Miocene time but was revived during the final folding of the Misoa anticline.

A parallel fault situated approximately 1 km. (0.6 miles) southwest of the Main Fault zone separates the El Veleto area from the higher parts of the structure and is responsible for trapping conditions in the Eocene of this area situated well down the plunge, in combination with stratigraphic trapping.

OIL AND GAS RESERVOIRS

(Figs. 12 and 13)

MIOCENE RESERVOIRS

Oil accumulation in the Miocene occurs mainly in the following zones, from top to bottom.

The *Tar sands* of the upper Younger Tertiary contain very heavy oil in practically all parts of the field, but commonly accompanied by intercalated water sands. It would be difficult to produce the oil because of this and the high viscosity, and at present no oil is obtained from the Tar sands. Gravity is about 10° A.P.I. (S. G. 1.0). On the west flank a buried zone of seepages is suspected at the unconformity at the base of the Tar sand. It seems to be closely connected with the Main Fault zone.

The *Upper Heavy Oil series* is composed of the upper and lower K, H, and G sands. The average gravity of the oil in these sands is 16.7° A.P.I. (S. G. 0.954). They are productive mainly in the south-central and western areas of the field.

The *Main Oil zone* is productive in most parts of the field, excepting on the

plunge. It is the main source of heavy oil which has an average gravity of 17.5° A.P.I. (S. G. 0.949).

The *Lower Sandy clays* ordinarily contain poor sands and only small amounts of oil are produced from them.

It is probable that there is gravity stratification of the oil in the Miocene reservoir but the grade of oil found in any one zone is not the same throughout the field. In general the oil is heavier in the crestal part and east flank of the field than on the west flank, especially in its southern part. This is almost certainly connected with the fact that all the Miocene sands are exposed in a belt of outcrops on the crest of the anticline and on the east flank north of the productive area (Fig. 15), while the accumulation on the west flank is trapped by the Main Fault zone and protected by the Tar sands. Seepages of heavy oil accompany the mentioned outcrops of the producing sands. The accumulation a short distance downdip from the outcrops is probably due to the sealing of the sands by asphalt, and the oil seems to be gradually lighter farther downdip.

The Main Fault zone was thus of great importance for the accumulation in the Miocene. It separates areas in which reservoir conditions are widely different, and this is evident from different production characteristics. East of the fault zone, production appears to be of simple depletion type accompanied by the formation of an expanding secondary gas cap in the crestal zone. On the west flank, on the other hand, the existence of a fairly strong water drive seems to be certain. Furthermore, the fault zone marks the boundary between medium oil production (S. G. 0.92–0.94) in the southern west flank and heavy oil (S.G. 0.94–0.97) in the crestal area. On the west flank itself gradually heavier oil is found toward the north (S.G. 0.94–0.96 in northern half).

The total thickness of the productive sands in the Miocene varies between 300 and 500 feet over an area of 6,800 acres (2,800 hectares). Porosity, according to the few determinations available, is approximately 27 per cent in the Heavy Oil zone, 31 per cent in the Main Oil zone.

EOCENE RESERVOIRS

Oil accumulation has been observed in three following formations.

The *Middle Paují sandstone* yields fair to good production of an average gravity of 23.3° A.P.I. (S.G. 0.914). Its connate-water content was determined as 25 per cent.

The *Lower Paují formation* contains sandy shales which gave some oil showings, but in view of their nature these beds have not been tested.

The *Misoa-Trujillo formation* is the main source of light crude in the Mene Grande field. It is subdivided into three separate zones.

(a) The *Transition zone* gives fair to good production of an average gravity of 25.7° A.P.I. (S.G. 0.90) in the Main Light Oil uplift and farther south.

(b) *The Main sandstone* was the chief producing zone in the Eocene but is now water-bearing in most areas. The gravity of the oil ranges from 24–31° A.P.I., and averages 25.7° (S.G. 0.90).

(c) The *Lower sandstones and shales* are the deepest producing zone. Only small quantities of oil are now obtained from it on the Main Light Oil uplift, together with considerable amounts of water. Gravity of the oil varies from 24° to 31° A.P.I. (S.G. 0.87–0.91).

Evidently in the Eocene also there is some gravity stratification of the oil, but there is no sharp gravity separation between Miocene and Eocene oils. In fact there is close similarity between the medium oils produced from the middle Paují sandstone and from the Miocene of the southern west flank.

Conditions which caused trapping in the Eocene reservoirs are partly tectonic, partly stratigraphic .The Main Light Oil uplift is a faulted dome, and faulting of a plunging anticline is responsible for accumulation in the MG-235 uplift and in the Misoa-Trujillo formation of the El Veleto area. However, changes in permeability may affect all these reservoirs. In the middle Paují sandstone trapping is mainly due to stratigraphic causes, namely, wedging of the sandstones and overlap by a transgressive formation, combined with tectonic conditions.

It is interesting to consider the latter case more closely. Accumulation is found in the middle Paují sandstone below the pre-Miocene erosional surface. In view of the relatively good permeability of the sandstone and the absence of any sign of heavy oil and asphalt near this surface, the oil must have been trapped by the transgressive Miocene (lower Sandy clays). Migration of the oil into its present position thus took place after the Miocene was deposited. This suggests that oil generating in the Eocene as a whole may have migrated slowly updip against the unconformity and where it did not find suitable reservoir conditions in the Eocene it may have migrated along the unconformity eventually finding its way into the Miocene. This would explain the close similarity of Eocene and Miocene oil and also the prolific oil content of the Miocene which is rather poor in organic matter and consists mostly of sands and mottled clays but does not include marine beds.

Production characteristics of the Misoa-Trujillo reservoirs are a strong water drive in the Main Light Oil uplift, the MG-235 uplift and the Veleto area. Well MT-1 on the Main Light Oil uplift which was drilled in 1930 has produced a total of 14,210,000 barrels of oil at the end of 1945 and was then still making 200 barrels daily.

In the middle Paují sandstone a strong water drive is indicated in the southern part of the west flank. The El Veleto area is believed to produce from the middle Paují by dissolved gas drive.

The total thickness of the productive sandstone in the middle Paují is estimated at 60–70 feet. In the Misoa-Trujillo formation the productive sands attain a thickness of 500 feet. Excluding the El Veleto area, in which limits of production have not yet been reached everywhere, the middle Paují sandstone is productive over 850 acres (250 hectares) and the Misoa-Trujillo formation over 2,050 acres (820 hectares).

Many core samples from the Eocene sandstones have been examined to de-

termine porosity and permeability. High permeabilities are exceptional in the Misoa -Trujillo sandstones, which are believed to produce chiefly from joints and fissures. The following are representative figures.

Formation	*Porosity Percentage*	*Permeability in Millidarcys*	
		Range	*Average*
Middle Paují sandstone	12	6.1–310	25–40
Misoa-Trujillo	10	0.1–350	1– 2

RESERVOIR FLUIDS

For refining purposes the crude oil produced in the Mene Grande field is segregated into two types: light-medium crude and heavy crude. The differentiation is based on both gravity and determination of the H.U.C.R. (highest useful compression ratio) of the gasoline fraction,[16] because the heavy crude contains better gasoline (octane value 65) than the light-medium crude (octane value 59), although in smaller quantity. The paraffine wax content is also taken into account, and as a rule oils with a wax content greater than 0.8 per cent and a H.U.C.R. smaller than 5.3 are assigned to the light-medium crude.

The characteristics of the Mene Grande crude oils are given in Table XVIII. Analyses of water from the Miocene and the middle Paují sandstone are given in Tables XIX and XX.

DRILLING AND COMPLETION PRACTICE

At present, three strings are in operation in the Mene Grande field, one drilling for Miocene oil on the west flank and two drilling for the Misoa-Trujillo and the middle Paují sandstones in the southern part of the field. In the west flank wells, $13\frac{3}{8}$-inch casing is cemented as surface string at 200 feet, $8\frac{5}{8}$-inch casing as water shut-off above the producing zones and $6\frac{5}{8}$-inch, 0.015-inch-gauge wire-wrapped screen liner is set against the oil sands. The interval to be produced is usually determined with the help of Schlumberger log and side-wall samples, in order to shut out overlying water sands and also bottom water. Drilling times for west flank wells vary between 1 and 2 months, in accordance with their location on the steep flank.

In the deep Eocene wells it was necessary until recently to use a $13\frac{3}{8}$-inch$\times 9\frac{5}{8}$-inch$\times 5\frac{1}{2}$-inch casing scheme because caving of the thick shale section of the Pauji formation presented many difficulties and required the setting of a $9\frac{5}{8}$-inch protection string some distance above the objective. These difficulties, however, are now considered to have been overcome by the use of an oil emulsion mud developed in Shell's laboratories in Venezuela, and it is proposed to use a $10\frac{3}{4}$-inch$\times 5\frac{1}{2}$-inch casing scheme, wells to be completed as open holes with the $5\frac{1}{2}$-inch casing cemented at the top of the productive formation. Some cores are taken to determine the fluid content of the sandstones. Middle Paují and the Misoa Trujillo wells require between 4 and 8 months for completion.

[16] European method approximately equivalent to determination of octane rating.

TABLE XVIII

CHARACTERISTICS OF MENE GRANDE CRUDE OIL

	Light-Medium	*Heavy*
GENERAL		
Type	Asphaltic	Asphaltic
Specific gravity range	.886 to .940	.940 to .970
A.P.I. gravity range	28.2° to 19.0°	19.0° to 14.8°
CRUDE OIL TAKEN FROM MAIN STORAGE AT SAN LORENZO ON APRIL 20, 1945		
Specific gravity 60/60°F.	0.9191	0.9488
A.P.I. gravity	22.4°	17.6°
Color by reflected light	Black	Black
Color by transmitted light	Dark brown	Dark brown
Viscosity Engler at 30°C.	8.24°	33.5°
Viscosity Engler at 50°C.	3.88°	13.0°
Flash point	Below 50°F.	Below 50°F.
Pour point test	Below 32°F.	Below 32°F.
Paraffine wax	1.23%	0.53°
Setting point of paraffine wax	56°C.	56°C.
Sulphur	1.9%	2.3%
Initial boiling point	72°C.	78°C.
CRUDE OIL RECEIVED IN SAN LORENZO REFINERY		
Yields by volume		
Gasoline	14.7%	10.3%
Gas oil	15.7%	7.5%
Fuel oil	69.6%	82.2%
PROPERTIES OF PRODUCTS		
Gasoline		
Specific gravity at 60°F.	748	762
Distilling up to 100°C. (A.S.T.M.)	21%	19%
F.B.P. (A.S.T.M.)	205°C.	206°C.
Octane number (C.F.R. Motor method)	59	65
Gas oil		
Specific gravity at 60°F.	846	856
Distilling up to 300°C. (A.S.T.M.)	85%	87%
Sulphur content	0.66%	0.80%
Diesel index	50.6	43.3
Fuel oil		
Specific gravity at 60° F.	977	988
Viscosity Engler	83	154

PRODUCTION

A total of 495 wells had been drilled in the Mene Grande field at the end of 1945. Of these, 270 were actually producing (flowing 12, pumping 196, gas-lift 62), 121 were abandoned, and the remaining wells were idle for various reasons (gas conservation, repairs, *et cetera*).

Initial production rates for west flank Micoene wells average about 600 barrels, and initials from the middle Paují and Misoa-Trujillo range from as little as 250 barrels to as high as 1,500 barrels, depending on the stratigraphical and structural conditions encountered. The monthly decline rate of the field as a whole is about 2 per cent.

TABLE XIX

ANALYSIS OF WATER FROM MIOCENE OF MENE GRANDE FIELD

Field:	Mene Grande	Date sample collected:	October 1, 1941
Well No.:	MG. 439	Date sample analyzed:	October 9, 1941
Depth:	2,890 feet	Method of sampling:	J.F.T. 1,915–1,935 feet

Color: Colorless, clear
Odor: Of petroleum acid soaps } After filtration
H_2S is not present.
Free CO_2 is not present
Naphthenic acids were not determined
Total alkalinity is equivalent to 3,088 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 137 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 137 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na'	1,802	78.33
Calcium	Ca''	30	1.50
Magnesium	Mg''	15	1.23
Positive sub-total			81.06
Chloride	Cl'	685	19.32
Sulphate	SO_4''	—	—
Carbonate	CO_3''	97	3.23
Hydrocarbonate	HCO_3''	3,570	58.51
Negative sub-total			81.06
Grand total		6,199	162.12

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	162 mgms.
Chloride salinity	100%
Primary salinity	24%
Primary alkalinity	73%
Secondary alkalinity	3%

Note: Sodium by difference
Remarks: Fluid level: 1,500 feet
Sample taken: 1,804–1,889 feet
Formation: Miocene
Date: October 11, 1941 Laboratory San Lorenzo

The field has reached the drilled-up stage in its central area, where a 231-meter triangular (approximately 11 acres) spacing was used, but many locations, which are considered to be proved, remain to be drilled on the edges of the heavy oil accumulation. The west flank was developed on a 400-meter triangular spacing (approximately 34 acres) with interspaced wells at 231 meters (11 acres).

In the Veleto area, the drilling has been confined so far, to 600-meter square spacing (90 acres). The limits of accumulation have not yet been fully determined in this area.

TABLE XX

ANALYSIS OF WATER FROM MIDDLE PAUJI SANDSTONE, MENE GRANDE FIELD

Field:	Mene Grande	Date sample collected:	July 20, 1945
Well No.:	MG-482	Date sample analyzed:	July 28, 1945
Depth:	8,360, plugged back 7,981 feet	Method of sampling:	While swabbing

Color: Light yellow, slight turbidity } After filtration
Odor: Musty
H_2S is not present
Free CO_2 is not present
Naphthenic acids were not determined
Total alkalinity is equivalent to 2,593 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 35 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 35 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na'	1,652	71.81
Calcium	Ca''	9	0.45
Magnesium	Mg''	3	0.25
Positive sub-total			72.51
Chloride	Cl'	695	19.60
Sulphate	SO_4''	51	1.06
Carbonate	CO_3''	108	3.60
Hydrocarbonate	HCO_3''	2,944	48.25
Negative sub-total			72.51
Grand total		5,462	145.02

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	145
Chloride salinity	95%
Primary salinity	28%
Primary alkalinity	71%
Secondary alkalinity	1%

Note: Sodium by difference
Remarks: Interval open: 7,960–7,974 feet
Formation: Upper sand of middle Pauji
Date: July 30, 1945 Laboratory San Lorenzo

The production statistics of the Mene Grande field are given in Table XXI, which shows that most of the oil is produced by artificial lift. Apart from the gas lift wells, there are five central pumping powers and the remaining wells are pumped by individual units with gas engines. Intermittent gas lift is employed on some of the shallow Miocene wells of the main field. A few wells with large water production from the Eocene are on straight gas lift.

No figures are available on original reservoir pressures in the different accumulations in the Mene Grande field, but for the Miocene it is estimated to have

TABLE XXI

PRODUCTION STATISTICS OF MENE GRANDE FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1917	200,000
1918	360,000
1919	200,000
1920	500,000
1921	1,510,000
1922	2,260,000
1923	3,270,000
1924	5,108,000
1925	6,303,170
1926	8,600,671
1927	10,029,458
1928	13,384,306
1929	15,280,256
1930	20,355,967
1931	11,690,013
1932	13,181,589
1933	12,712,044
1934	15,012,576
1935	15,378,445
1936	15,377,444
1937	14,348,844
1938	12,252,435
1939	12,235,405
1940	10,812,402
1941	12,496,698
1942	10,240,389[1]
1943	10,651,138
1944	11,701,610
1945	12,831,103
Total	278,283,963

PRODUCTION DURING DECEMBER, 1945

LIGHT-MEDIUM OIL

	Total Production (Barrels)	*Daily Average Production (Barrels)*	*Daily Potential (Barrels)*	*Number of Producing Wells*
Flowing		1.820	1.833	6
Gas lift		446	446	6
Pumping		8.570	8.570	41
Total	336.259	10.836	10.849	53

HEAVY OIL

	Total Production (Barrels)	*Daily Average Production (Barrels)*	*Daily Potential (Barrels)*	*Number of Producing Wells*
Flowing		1.820	1.820	5
Gas lift		2.925	2.925	56
Pumping		20.270	20.270	158
Total	777.067	25.015	25.015	219

[1]Affected by adverse shipping situation.

been approximately 1,100 pounds per square inch at the base of the Main Oil zone at an average depth of 2,500 feet. A bottom-hole-pressure survey was made for the first time in 1940. It was repeated in 1941 but not since. Pressures at the mentioned level and average depth varied then between 380 and 600 pounds per square inch. Some years ago a gas repressuring scheme was tried, but was abandoned as no benefit could be ascertained from the experiment.

Average gas-oil ratio of the field is about 365 cubic feet per barrel. Gas-oil

TABLE XXII

AVERAGE DAILY PRODUCTION OF GAS IN MENE GRANDE FIELD DURING DECEMBER, 1945, AND ITS APPLICATION, IN CUBIC FEET

Total production	Fuel for field operations	To San Lorenzo refinery for fuel
25,666,000	5,605,000	2,693,000
	Burned in flares	Fuel for field operations
	1,666,000	1,909,000
	Compressor plant	For straight gas lift
		1,207,000
	Intake → Output	
	18,395,000 → 12,876,000	For intermittent gas lift
		6,234,000
	Casing-head gasoline: 418 bbls.	Shellane gas: 1.16 metric tons
		Losses: 833,000

ratios are generally low in the Miocene, but figures as high as 5,600 cubic feet per barrel have been recorded. In the Eocene, the maximum gas-oil ratio on the flanks of the structure is about 1,200 cubic feet per barrel.

The average daily amount of gas produced during December, 1945, was 25,666,000 cubic feet. Details on the uses of the gas are given in Table XXII. High-pressure gas from a large compressor plant is used for gas-lift work, and as fuel for the San Lorenzo refinery. During December, 1945, 12,774 barrels of casing-head gasoline were recovered in the plant. This gasoline is pumped through a separate line to San Lorenzo where it is blended with heavy gasoline and shipped to Curaçao. The same plant turns out compressed gas for domestic use which is marketed in steel cylinders throughout Venezuela under the trade name "Shellane."

The presence of water in many wells entails the maintenance of a large de-

hydration system. The Eocene oil is produced together with a large quantity of water, forming a tight emulsion with the oil. Of a daily total of 5,500 barrels of fluid pumped into the dehydration system, only 1,500 barrels are clean oil. Most of this light-oil emulsion is treated with Turkey Red Oil and Tretolite. The medium oil is dehydrated in a Petreco electrical plant and at present some light oil is also being pumped into this plant. The heavy oil is treated with lime. In the near future all wet oil will be treated in the electrical units.

Good potable water is found above the oil levels in certain parts of the field, and is used for domestic purposes. Water is also obtained from a river near the field and is pumped to the San Lorenzo refinery.

All the oil produced in the Mene Grande field is pumped to San Lorenzo through two 8-inch pipelines, one for heavy, the other for medium-light oil. San Lorenzo is the site of the loading terminal and the refinery, which has a throughput of about 30,000 barrels daily. Most of the refined products are used to supply the Venezuelan market, but surplus crude and some refined products are shipped to Curaçao. The refinery residue (heavy fuel) is also sent to Curaçao.

Part IV. Fields in Maracaibo and Mara Districts

La Concepción Field

SITUATION AND DEVELOPMENT

The Concepción field is situated 24 km. (15 miles) west of Maracaibo in the Maracaibo District (Fig.1). It is linked to Maracaibo by an oiled road built by the Venezuelan Oil Concessions Limited.

The field is located on a peneplain which extends from the foothills of the Perijá Range to the western shore of Lake Maracaibo and is covered by savannas and the forest typical for dry country with short rainy seasons. The elevation is approximately 230 feet above sea-level. The terrane presents no practical difficulties.

The field was discovered as the result of geological investigations. Very low hills formed by the Miocene surround the crest of the La Concepción structure on which Eocene beds are near the surface. Pitting in the crestal zone revealed the presence of an anticline complicated by faulting.

There are no seepages at La Concepción, but attention had been attracted to the area in general by the seepages at La Paz and along the foothills of the Perijá Range.

Drilling was started in 1924 with cable tools and exploitation began in 1925 upon completion of the pipe line. Development was suspended in 1927 after 65 wells had been drilled with cable tools, and only sporadic drilling with rotary rigs was carried out from 1930 to 1940. Active drilling for increased production was taken up once more in July, 1941, but was suspended again in April, 1944, due to the rapid production decline of the newly completed wells.

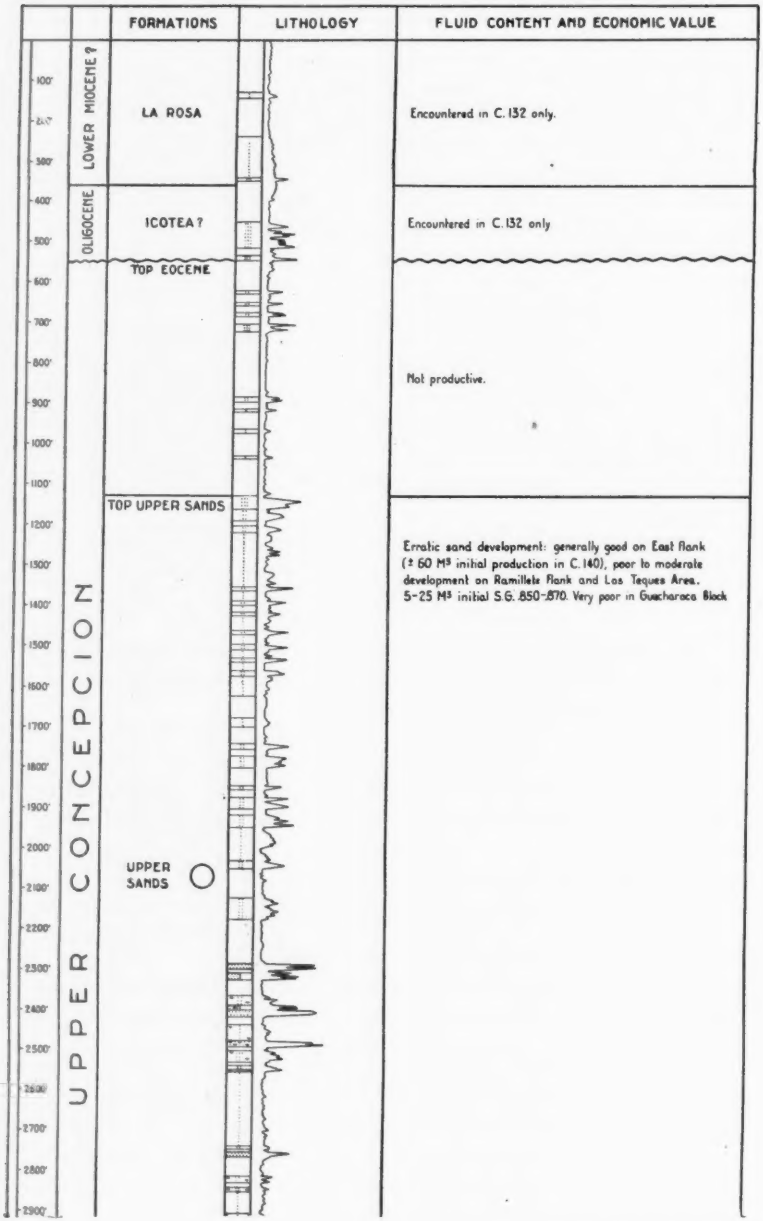
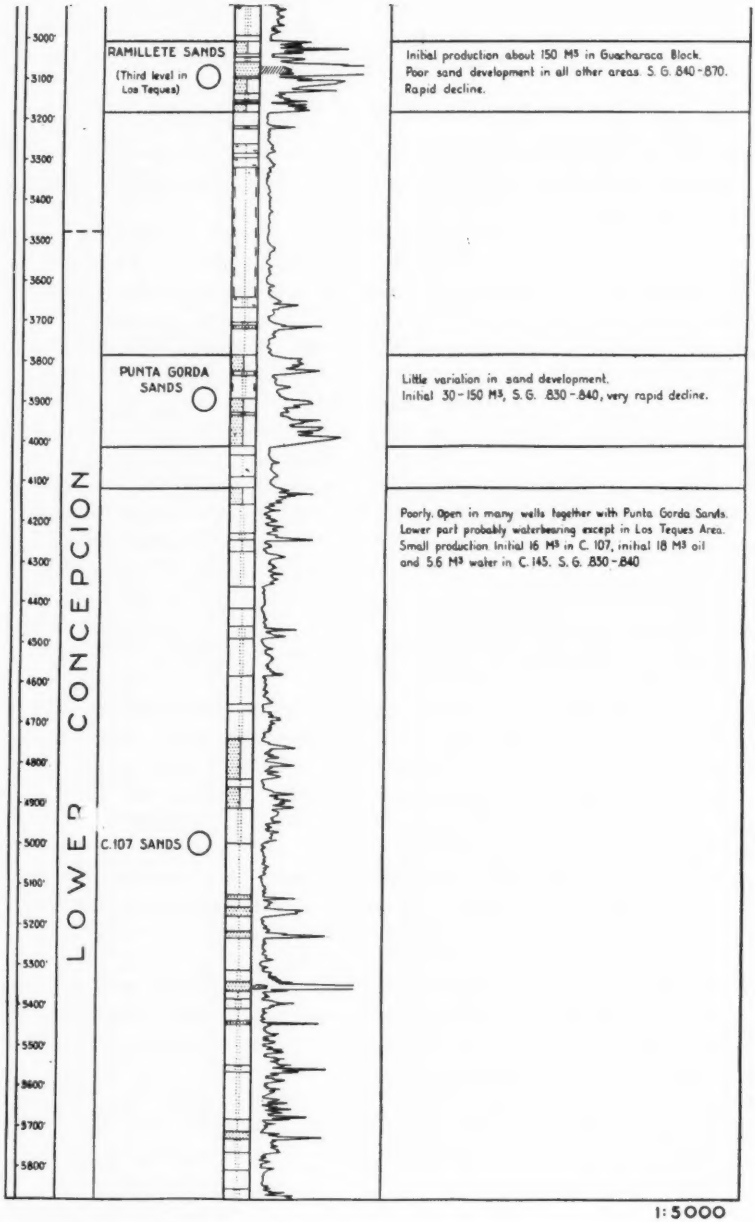


FIG. 17.—Type section of La Concepción



field. Circles indicate productive zones.

The whole Concepción field is situated on concessions held by the Venezuelan Oil Concessions Limited.

STRATIGRAPHY

(Fig. 17)

The formations observed so far in and around the Concepción field belong to the Eocene and the Miocene.

EOCENE

The Eocene consists of a rather monotonous series of dark gray shales, dark gray, micaceous, carbonaceous sandy shales and gray sandstones. The sandstones occur in irregular lenses and beds varying in thickness from several millimeters to several meters throughout the section. Grain size varies from very fine to coarse. Two better defined sandstone bodies are called the Ramillete sands and Punta Gorda sands after structural units of the field in which they are the main producing beds.

The Eocene perforated at La Concepción is subdivided into upper and lower Concepción formation. The division between the formations is rather indeterminate and is placed arbitrarily in the shale group between the Punta Gorda sands and the Ramillete sands. Characteristics of the upper Concepción formation are the common presence of a foraminiferal fauna of brackish type composed of several *Trochammina* and *Agathammina* species, and of pebbled garnet, while etched garnets are predominant in the faunally poor lower Concepción formation.

It has not yet been possible to correlate these formations over large distances but at present it seems probable that the Concepción formation corresponds with the lower Micaceous sandstone in the Bolivar District and to part of the Paso Diablo and Mostrencos formation[17] in the Dibujo synclinorium.

All production of the Concepción field is derived from the Eocene, mainly from the Ramillete and Punta Gorda sands, to a small degree from the Upper sands (upper Concepción formation above the Ramillete sand) and from the so-called C-107 sands (lower Concepción formation below Punta Gorda sand).

MIOCENE

Most wells of the Concepción field started drilling in the Eocene, and knowledge of younger formations is therefore very scanty. So far three formations of Miocene age or younger have been found, from top to bottom: Maracaibo series, La Rosa formation, and Icotea formation.

Icotea and La Rosa formations.—The presence of the La Rosa formation on the southeast flank of the Concepción anticline (Punta Gorda flank) was proved by faunal evidence in one well (C-132). It consists of bluish green shales and may reach a thickness of 365 feet.

[17] See H. D. Hedberg and L. C. Sass, *op. cit.*

In view of the lithological resemblance to the Icotea formation of the Bolivar District, a group of sands showing on the electrical log of the same well between the Eocene and the La Rosa is thought to belong to this formation. The two formations presumably overlie the Eocene unconformably and in turn are cut off by the transgression of the Maracaibo series, as they have not been found at the surface.

Maracaibo series.—The Maracaibo series consists of a thick series of mottled, massive clay or sandy clay with a few sand intercalations. It has a wide extent in the Mara and Maracaibo districts and is known to transgress with a basal conglomerate over Eocene and Cretaceous down onto the pre-Cretaceous basement in the western parts of these districts. This series is present in La Concepción where it transgresses onto the Eocene and presumably over the Icotea and La Rosa formations and forms the low hills surrounding the field. It has been involved in the last phase of folding and is therefore tentatively placed in the Miocene but so far no fossils allowing an age determination have been found. It is thought to be the equivalent of the Lagunillas and La Puerta formations of the Bolivar District and of the Los Ranchos and La Villa formations known in the Perija District.[18]

STRUCTURE

(Figs. 18 and 19)

Structurally, the field is located on a steeply folded anticline which is strongly disturbed by longitudinal faulting and, to a less degree, by cross faults. The Concepción structure is divided by these faults into five main structural units which are: South Concepción structure, Los Teques structure, Ramillete flank, Punta Gorda structure, and Guacharaca block.

Correlation within and between the structural blocks is mainly based on Schlumberger logging, to some extent on micro-palaeontological and heavy-mineral investigation. The *South Concepción structure* is the symmetrical plunge of the anticline. It has a flat apex several hundred meters wide and steep flanks. The structure appears to be moderately favorable for oil accumulation, but little oil has yet been produced in this block because of insufficient exploration.

Los Teques structure is believed to be the highest uplift of the La Concepción anticline. It is a steeply folded anticline on which the crest is down faulted with respect to the flanks. The early development of the field was confined to this structural unit.

The Ramillete flank has the best sand development and therefore supplied the bulk of the Concepción production. It is part of the northwest flank of the structure which dips here approximately 25° and is probably divided into several blocks by cross-faults. It is downthrown with respect to the Los Teques block.

The *Punta Gorda structure* comprises the crest and the southeast flank opposite the Ramillete and Guacharaca blocks of the northwest flank, and is separated

[18] See H. D. Hedberg and L. C. Sass, *op. cit.*

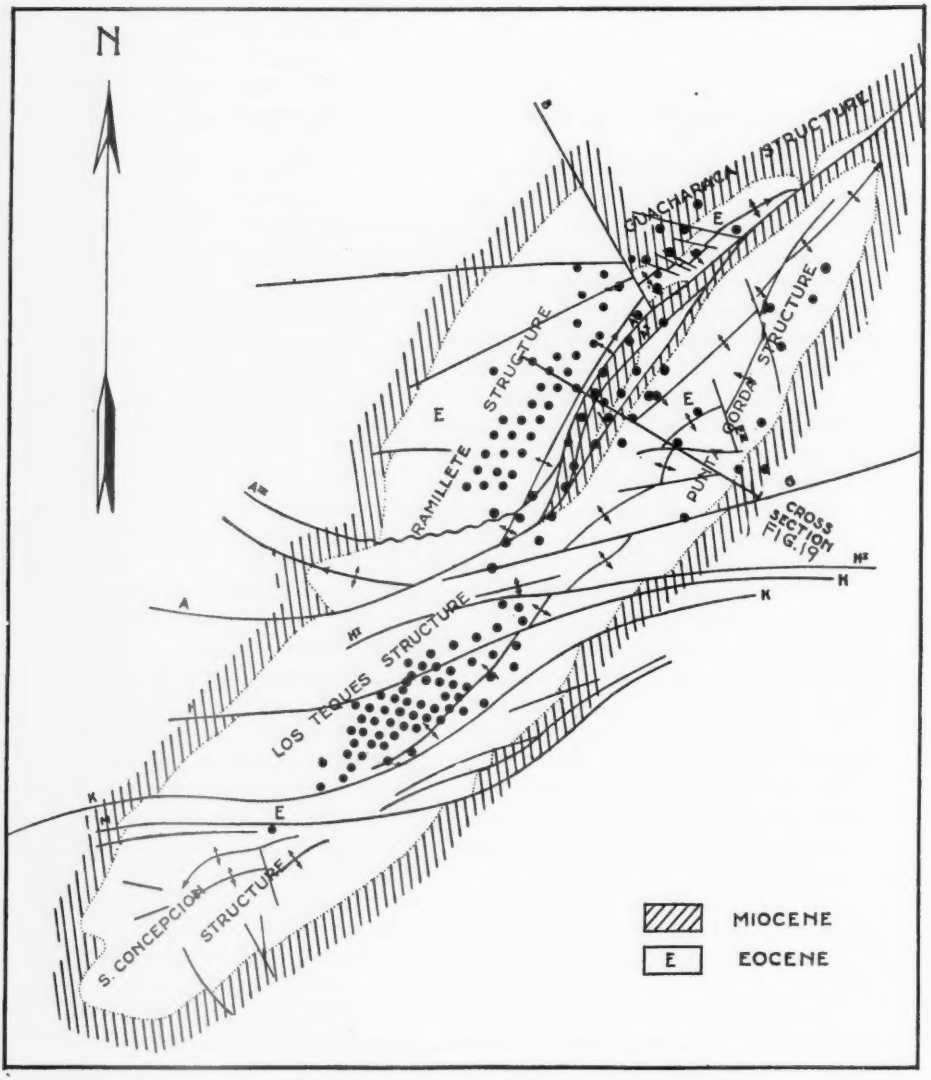


FIG. 18.—Tectonic map of La Concepción field, according to L. U. de Sitter. Scale, $\frac{3}{4}$ inch = 1 kilometer.

from them by a series of crest faults. In the central part of the structure, the crest faults dip 45°–50° toward the southeast; but in the north, their hade is probably much steeper. Displacement is normal, that is a southeasterly downthrow, which brings the crest of the structure to approximately the same height as the upper edge of the Ramillete flank. The dip of the Punta Gorda flank is about 50°.

The *Guacharaca block* is the northernmost part of the northwest flank which dips here approximately 50°. It is somewhat downthrown along a cross fault with respect to the Ramillete flank.

OIL AND GAS RESERVOIRS
(Fig. 17)

The oil and gas produced in the Concepción field is obtained from sands of Eocene age which are now divided into three main oil zones as follows.

The *Upper sands* include all the lenticular sands found above the Ramillete sand and, together with this sand, constitute so far the main productive levels in the Los Teques structure. They are also oil-bearing on the Punta Gorda flank and on the Ramillete flank.

The *Ramillete sands* have been the most prolific oil level in La Concepción. It consists of several sandstones which, on the Ramillete structure, have a total thickness of about 180 feet. Average initial production on the Ramillete structure has been about 1,000 barrels but decline is rapid. Average porosity of the sandstone is 21 per cent and permeability measurements indicated values up to 600 millidarcys. Total recovery from this sand which is well developed only on the Ramillete flank has been high, with gravity ranging from 33° to 36° A.P.I. (S.G. 0.860-0.844).

The *Punta Gorda sands*, which have only been exploited in recent years, have given an average initial production of about 380 barrels daily, but decline is very rapid in the early stages. They consist of a series of sandstones totalling approximately 220 feet in thickness. Core samples have an average porosity of 18.5 per cent and permeability ranges up to 300 millidarcys. A series of thin, lenticular sands (C-107 sands) occurs below the Punta Gorda sands, but is usually produced together with the Punta Gorda sands.

DRILLING AND COMPLETION PRACTICE

There has been no drilling in La Concepción since 1944. The last wells drilled had depths varying from 3,500 feet to 4,500 feet, and were completed in two to five weeks with an $8\frac{5}{8}$-inch surface string cemented at about 100 feet. and a 5-inch combination oil string cemented through ports above the top of the sands to be taken into production. Later on, in many wells the casing was gun perforated for production from the more promising sand bodies in the Upper sands. The majority of the wells could be drilled with a Franks portable outfit, although in the deeper wells steam rigs had to be employed.

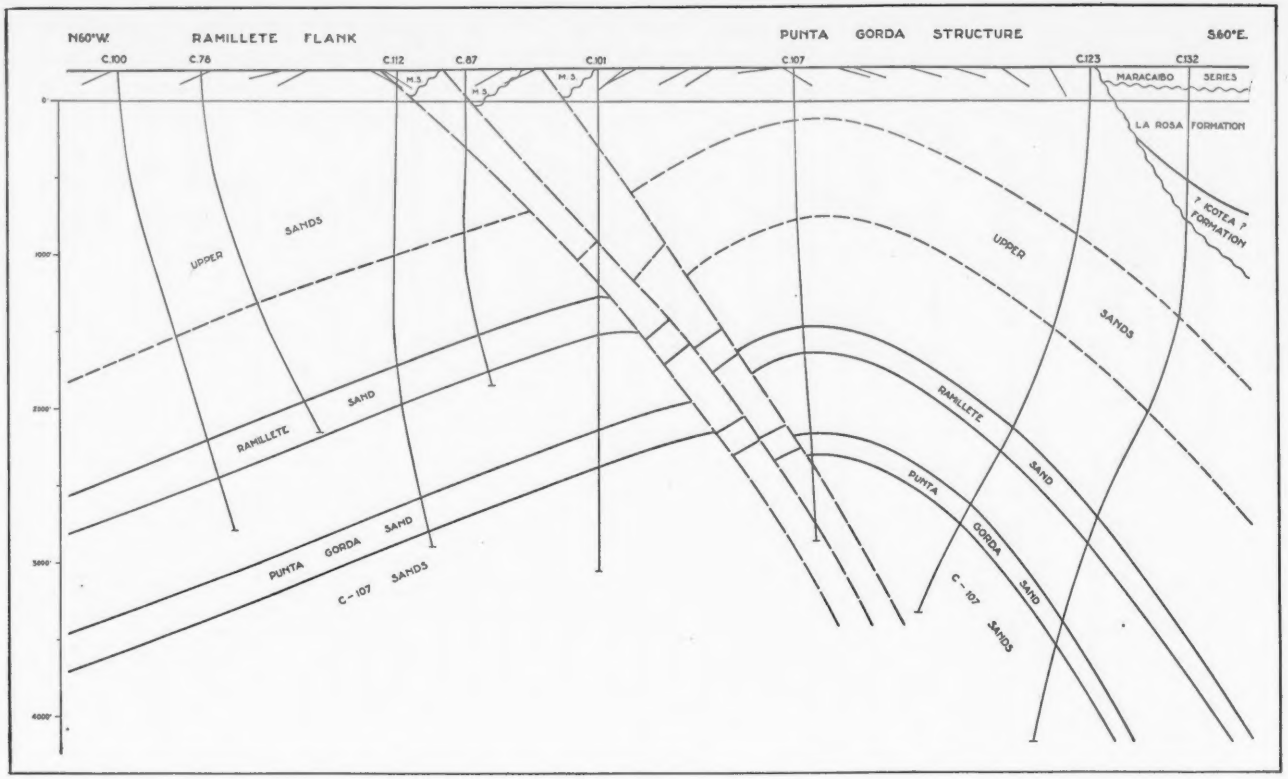


FIG. 19.—Cross section through Ramilette flank and Punta Gorda structure of Concepción field, according to P. de Schumacher. Vertical and horizontal scales equal.

Little coring for structural information has been done in recent wells, as correlation has been possible by means of Schlumberger electrical logging. Gamma-ray surveys were made in some wells of the field, mainly in the Los Teques area which had been drilled before electrical logging became available.

PRODUCTION

A total of 147 wells had been drilled in La Concepción at the end of 1945.

TABLE XXIII

PRODUCTION STATISTICS OF LA CONCEPCIÓN FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1925	348,283
1926	862,644
1927	565,480
1928	—
1929	79,785
1930	3,199,043
1931	4,574,011
1932	2,094,854
1933	2,096,352
1934	1,737,874
1935	1,404,775
1936	1,149,498
1937	1,031,764
1938	918,133
1939	879,156
1940	838,967
1941	1,203,405
1942	1,709,608
1943	1,712,281
1944	1,357,774
1945	1,355,106
Total	29,118,793

PRODUCTION DURING DECEMBER, 1945

	Total Production (Barrels)	*Daily Average (Barrels)*	*Daily Potential (Barrels)*	*No. of Producing Wells*
Flowing		263	263	3
Pumping		3,115	3,115	90
	104,838	3,378	3,378	93

Ninety-three of them were actually producing (flowing 3, pumping 90), 34 had been abandoned, and the remaining wells were not producing for various reasons (repairs, gas conservation).

In the Los Teques area there remains only one flowing well; the others are pumped by two central pumping powers, as wells in this part of the field are shallow. Most of the wells on the Ramillete flank are now also produced on the pump. There is a gas cap on the crest of the Ramillete flank in the Ramillete sands, and some wells located in this area are closed due to high gas-oil ratio.

TABLE XXIV

CHARACTERISTICS OF LA CONCEPCIÓN CRUDE OIL

GENERAL	
Type	Paraffinic
Specific gravity range	0.820 to 0.870
A.P.I. gravity range	41° to 31.1°
CRUDE OIL TAKEN FROM MAIN STORAGE, APRIL, 1945	
Specific gravity 60/60°F.	0.8451
A.P.I. gravity	35.9°
Color by reflected light	Dark green
Color by transmitted light	Dark green
Viscosity Engler at 30°C.	1.54°
Viscosity Engler at 50°C.	1.29°
Flash point	Below 50°F.
Pour point test	Below 32°F.
Paraffine wax	3.077
Setting point of paraffine wax	56°C.
Sulphur	0.70%
Initial boiling point	85°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945	
Yields by volume	
Gasoline	25.56%
Gas oil	30.63%
Fuel Oil	42.81%
PROPERTIES OF PRODUCTS	
Gasoline	
Specific gravity at 60°F.	0.747
Distilling up to 100°C. (A.S.T.M.)	17½%
F.B.P. (A.S.T.M.)	205°C.
Octane number (C.F.R. Motor method)	49
Gas oil	
Specific gravity at 60°F.	0.831
Distilling up to 300°C. (A.S.T.M.)	75%
Sulphur content	0.23%
Diesel index	64.8
Fuel oil	
Specific gravity at 60°F.	0.907
Viscosity Redwood I at 100°F.	581 sec.

Wells showed initial productions of 600–1,000 barrels per day when drilling was last done but decline was rapid and the pumping stage was very soon reached. Thereafter, however, the decline rate became almost negligible. Over-all decline rate of the Concepción field is now about 1 per cent monthly. At the end of 1945 the daily potential was approximately 3,400 barrels, and the field was produced to capacity. Table XXIII contains production statistics and the characteristics of the Concepción crude oil are given in Table XXIV.

To date there is no incursion of edge water, with the possible exception of the Ramillete sands where some slight encroachment is suspected. In general, the field is producing by gas drive. Water production is small and presents no problem as the water settles by itself in the flow tanks.

Gas-oil ratios are generally high, and on the flanks of the structure values ranging from 17,000 to 40,000 cubic feet per barrel of oil have been registered. A considerable amount of gas is produced, and in 1940 the Venezuelan Oil Concessions Limited contracted with the Venezuelan Government to provide the town of Maracaibo, free of charge, with gas for domestic and industrial uses, in line with the Royal Dutch Shell Group's policy of assisting in local progress whenever possible. The amount of gas stipulated in the contract is approximately 35,300,000 cubic feet per month.

The average daily amount of gas produced during December, 1945, was 5,750,00 cubic feet, of which 1,413,000 cubic feet were utilized in the field or delivered to Maracaibo. Of the latter volume the field used 695,000 cubic feet and Maracaibo received 718,000 cubic feet.

The gas which is delivered to the city of Maracaibo has the following approximate composition.

		Percentage
Carbon dioxide	(CO_2)	2.8
Methane	(CH_4)	70.9
Ethane	(C_2H_6)	8.2
Propane	(C_3H_8)	8.2
Butanes	(C_4H_{10})	6.2
Pentanes and heavier		3.7

The specific gravity of the gas as it comes from the well is about 0.89 (air = 1). The lower heating value is approximately 11,000 kilo calories per cubic meter (approximately 300 kilo calories per cubic foot).

The first bottom-hole-pressure survey was made in 1927, the last complete survey in 1941. No figures of the original reservoir pressure are available, but it is estimated that it was approximately 850 pounds per square inch at the top of the Ramillete sands at an average depth of 2,000 feet. In 1941 pressure had dropped to zero at the same level in some wells on the Ramillete flank. An experiment was made at that time to put some of the surplus gas back into the reservoir under pressure, but was discontinued after several months as uneconomical since the gas blew through to the lower structural wells quickly and no improvement in recovery became apparent. Furthermore, the injection pressures required were very high.

The proved area of the Concepción field is about 1,000 hectares (2,470 acres). Wells have been drilled on various spacing patterns with distances of 120–250 meters (3–12 acres). A few locations remain to be drilled but, due to the sharp decline experienced in the more recent wells, further drilling for Eocene production is not considered at present. The field has, however, good prospects of production in deeper levels, notably the Cretaceous.

The Concepción oil is pumped to the Punta Piedras Terminal on Lake Maracaibo, which is 25 km. (15.6 miles) from the field and a short distance south of Maracaibo. From there it goes by shallow-draft tanker to Curaçao for refining.

Drinking water for La Concepción and La Paz is produced from several shal-

TABLE XXV

ANALYSIS OF WATER FROM LA CONCEPCIÓN FIELD

Field:	La Concepción	Date sample collected:	February 4, 1944
Well No.:	C-145	Date sample analyzed:	February 18, 1944
Depth:	4,216 feet	Interval open:	2,265–4,200 feet

Color: Colorless, clear
Odor: Of petroleum acid soaps } After filtration
H_2S is not present
Free CO_2 is not present
Naphthenic acids were not determined
Total alkalinity is equivalent to 1,600 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 189 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 189 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil mgms. $CaCO_3$ per liter

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na′	4,703	204.47
Calcium	Ca″	49	2.45
Magnesium	Mg″	16	1.32
Positive sub-total			208.24
Chloride	Cl′	6,250	176.25
Sulphate	SO_4″	—	—
Carbonate	CO_3″	24	0.80
Hydrocarbonate	HCO_3″	1,903	31.19
Negative sub-total			208.24
Grand total		12,945	416.48

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	416
Chloride salinity	100%
Primary salinity	85%
Primary alkalinity	13%
Secondary alkalinity	2%

Note: Sodium by difference
Horizons open: Punta Gorda sands and deeper sands

Laboratory San Lorenzo

low wells near Punta Piedras, and is pumped to the fields through a 5-inch pipe line. The gas line for the supply of Maracaibo with gas from La Concepción is 27 km. (17 miles) long and consists of 6-inch welded pipe line.

LA PAZ FIELD

SITUATION AND DEVELOPMENT

The La Paz field is situated in the Maracaibo District, about 45 km. (28 miles) west of Maracaibo, and 20 km (12.5 miles) west and slightly north of the

Concepción field (Fig. 1). An oil road built by the Venezuelan Oil Concessions Limited connects the two fields, which are under one administration situated in La Concepción.

La Paz is located on the peneplain which extends from the foothills of the Perijá Range to the shore of Lake Maracaibo. The elevation is approximately 230 feet and the terrane presents no practical difficulties.

The field was discovered as the result of geological investigations. A large zone of seepages accompanies the crest of the La Paz structure and made the area conspicuous to the early geologists. Eocene and Cretaceous (Guasare formation) reach the surface on the highest part of the anticline.

Drilling started in 1922 with cable tools, and the field came into production from shallow sands in 1925 upon completion of the pipe line. Drilling was suspended in 1927 after 30 wells had been completed. It was resumed in 1930 with rotary equipment, but was suspended again after four wells had been drilled.

In 1942 drilling was resumed to increase the production of light oil from the La Paz field. In 1944 a test which was drilled beyond the shallow levels then in exploitation resulted in the discovery of prolific accumulation in the lower part of the Cretaceous section.

A detailed seismic survey of the structure was carried out during the same year. The top of the Cretaceous was contoured on seismic reflections and the resulting map has served as a guide for subsequent outstepping and deep drilling.

The entire field is situated on concessions held by the Venezuelan Oil Concessions Limited.

STRATIGRAPHY

(Fig. 20)

The formations present in the La Paz field belong to the pre-Cretaceous basement, the Cretaceous, and the Tertiary.

PRE-CRETACEOUS

The pre-Cretaceous basement was reached in well P-79 where it consists of granodiorite according to determinations by José Mas Val, mineralogist of the Creole Petroleum Corporation, Maracaibo. This rock is dark gray, coarse- to fine-grained, and is strongly weathered in the uppermost 6 feet, where it has a greenish brown color. The weathered zone is immediately overlain by 32 feet of coarse grits and sands, which at the base consist to a great extent of coarse angular to subangular quartz grains derived from the granodiorite. These grits and sands represent the base of the Cretaceous which clearly lies transgressively on an old erosional surface, and the age of the granodiorite is thus pre-Cretaceous.

CRETACEOUS

The Cretaceous of La Paz is subdivided into the following formations, from top to bottom: Guasare formation, La Paz shales, basal Colón limestone, La Luna formation, and Cogollo formation.

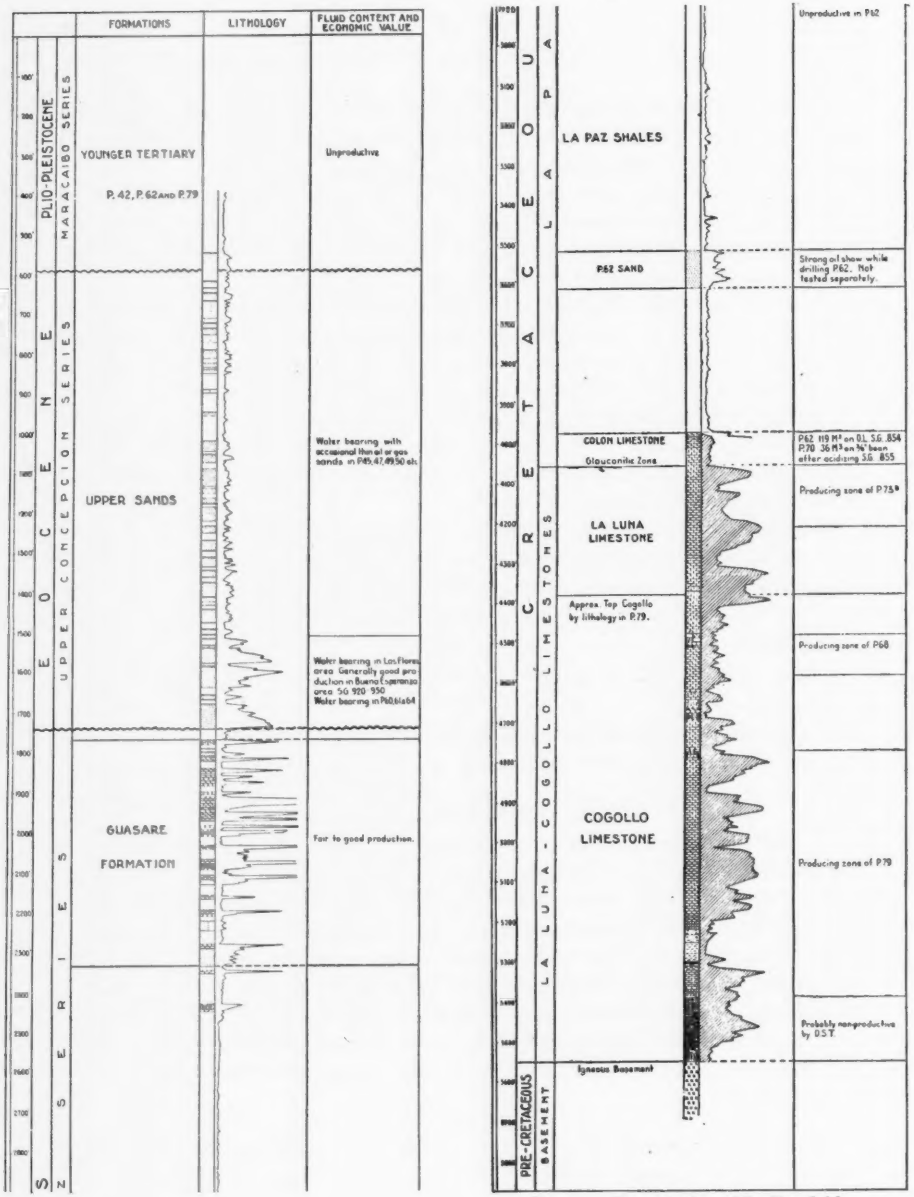

FORMATIONS
LITHOLOGY
FLUID CONTENT AND ECONOMIC VALUE
SERIES
NEOCENE
PLIO-PLEISTOCENE
MARACAIBO SERIES
UPPER CONCEPCION SERIES
YOUNGER TERTIARY
P. 42, P. 62 AND P. 79
Unproductive
UPPER SANDS
Water bearing with occasional thin oil or gas sands in P45, 47, 49 50 ats.
Water bearing in Los Flores area. Generally good production in Buena Esperanza area 56 920 950
Water bearing in P60, 61 & 64
GUASARE FORMATION
Fair to good production.
CRETACEOUS
LA LUNA - COGOLLO LIMESTONES
LA PAZ SHALES
P62 SAND
COLON LIMESTONE
Glauconitic Zone
LA LUNA LIMESTONE
Approx. Top Cogollo by lithology in P.79.
COGOLLO LIMESTONE
Igneous Basement
PRE-CRETACEOUS BASEMENT
Unproductive in P62
Strong oil show while drilling P62. Not tested separately.
P62 119 M³ on 0L. S.G. .854
P.70 36 M³ on ¾" bean after acidizing S.G. .855
Producing zone of P.75
Producing zone of P68
Producing zone of P.79
Probably nonproductive by D.S.T.

FIG. 20.—Type section of La Paz field.

Basal Colón limestone, La Paz shales, and the Guasare formation together are sometimes also called La Paz series.

The assignation of the Guasare to the Cretaceous is somewhat arbitrary and should not be considered as final. Several authors[19] have placed the Guasare in the Paleocene and some have claimed that it is transgressive. However little evidence has been adduced for the latter assertion, and it is the writer's opinion that sedimentation was not interrupted in the Mara and Maracaibo districts at the end of the Cretaceous. It is difficult to determine the boundary between Cretaceous and Tertiary in this area as fossil evidence is scanty but one is admittedly tempted to consider the strong, though gradual facies change from the La Paz Shales to the Guasare formation as an argument to place the whole Guasare in the Paleocene.[20] This question can, however, only be solved by thorough paleontological and stratigraphical studies, and until they are forthcoming the Guasare has been temporarily assigned to the Cretaceous.

Cogollo formation.—The Cogollo formation transgresses over the basement with some basal grits and sands. The Tomón or Uribante formation, which is the earliest Cretaceous formation known in the Tarra fields, the Barco Concession (Colombia) and the Mérida Andes, is absent in La Paz.

The Cogollo formation consists mainly of massive, non-bedded and commonly fossiliferous limestones. A great part of it is sand-streaked and has a reworked aspect which seems to indicate disturbed sedimentation. A well defined marl layer of 100 feet thickness at the top of the lower third subdivides the formation.

La Luna formation.—Approximately 330 feet of black, thin-bedded to slaty, marly limestone with intercalated beds of gray, crystalline limestone, and limestone concretions of varying sizes compose the La Luna. Fossil remains are abundant (globigerinids, *Inoceramus*, fish remains) and the whole formation is highly bituminous.

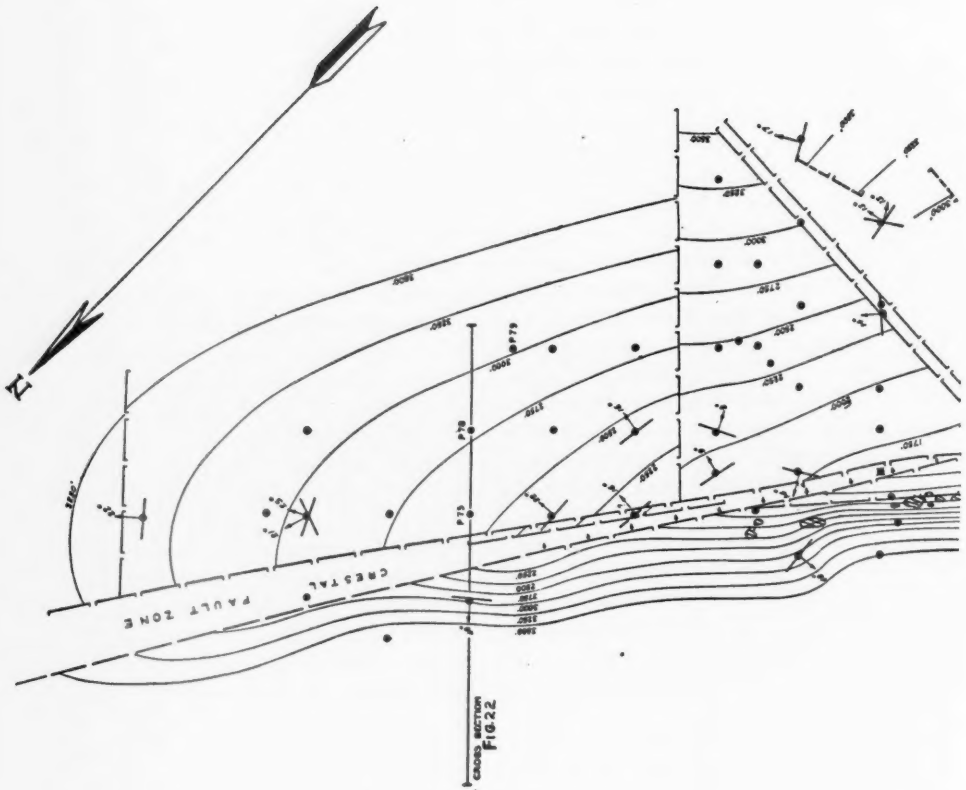
Basal Colón limestone.—A sharp facies change accompanied by a thin glauconite bed marks the beginning of a new series which overlies the La Luna formation conformably. At the base of this so-called La Paz series we find the basal Colón limestone which consists of the glauconite zone (18 feet) and of 65 feet of light gray, marly limestone. Together with the lower third of the overlying La Paz shales, it corresponds closely with the Colón formation of the Tarra fields, hence its name.

The glauconite zone is a regional feature in western Venezuela. The basal Colón limestone has been observed only in wells in the Mara and Maracaibo districts and in outcrops along the Sierra de Perijá. It contains practically the same fauna as the lower part of the La Paz shales.

La Paz shales.—The La Paz shales reach a maximum thickeness of 2,000

[19] H. D. Hedberg and L. C. Sass, *op. cit.* R. A. Liddle, *op. cit.* (1943). F. A. Sutton, "Geology of Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10 (October, 1946).

[20] H. P. Schaub, "Outline of Sedimentation in Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 2 (February, 1948), pp. 215–27.


N
CREST
FAULT ZONE
CROSS SECTION
Fig. 22

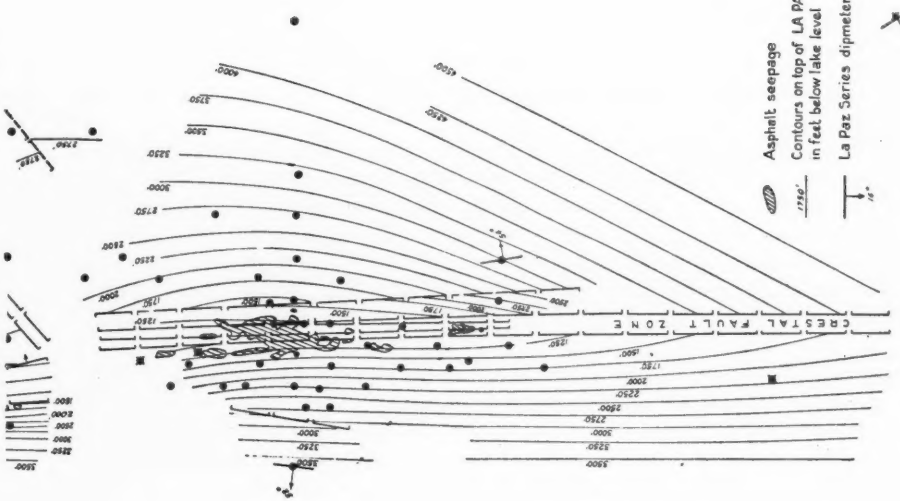

Asphalt seepage
Contours on top of LA PAZ SHALES in feet below lake level
La Paz Series dipmeter results
CRESTAL FAULT ZONE

FIG. 21.—Structural map of La Paz field. Approximately 1¼ inches = 1 kilometer.

feet which is generally somewhat reduced in La Paz, probably due to faulting. They consist of dark gray shales in which a thin sand zone (P-62 sand) is intercalated in some places about 350 feet above the base of the shales. The lower third of the formation contains a rich marine foraminiferal fauna which allows close correlation with the Colón formation, The upper two thirds are faunally much poorer and correspond with all or part of the Mito Juan formation.

Guasare formation.—The Guasare formation consists of lenticular sands, calcareous sandstones, and sandy shales with thin limestone intercalations. The limestones which are fossiliferous and commonly glauconitic are estimated to amount to 10–15 per cent of the formation which has a maximum thickness of 1,150 feet. Ostracods comprise a considerable part of the fauna. Correlation with the Guasare formation of the Dibujo synclinorium is based on lithologic resemblance and similar stratigraphic position.

TERTIARY

The Tertiary formations present in La Paz belong to the Eocene or the Miocene.

Eocene.—The Eocene is represented by a group of interbedded sandstones and sandy shales which are usually called Upper sands. The presence of many coal seams is typical for the lower part of the Upper sands, in which sands are predominant.

Comparison of logs from different parts of the La Paz field indicate that the Eocene lies unconformably on the Guasare formation, which is considerably thinner on the east flank than on the west flank of the anticline.

The maximum observed thickness of the Eocene is about 1,650 feet. It is generally assumed that the Upper sands correspond with part of the Eocene present in the La Concepción field, but there is insufficient evidence to allow a close correlation.

Miocene.—The Maracaibo series, described previously, transgresses on the Eocene at La Paz, where older Miocene formations are not present.

STRUCTURE

(Figs. 21 and 22)

The La Paz field is located on a crest-faulted, southwest–northeast anticline with a steep northwest flank and a less inclined southeast flank. The anticline is narrow in the southern part of the field and even the southeast flank dips between 50° and 60° in a narrow zone near the crest. Farther north the structure widens and the southeast flank dips only about 20°.

The northwest flank is steep everywhere in the narrow zone from which well information is available, and the dip varies between 50° and 70°. Seismic surveys indicate, however, that this steep zone is only about 1 km. wide and then flattens abruptly.

The crest of the anticline is shattered by a series of longitudinal faults, which

appear to dip steeply southeast. The throw of the crestal faults is not well defined, but appears to be small. Downthrow seems to be toward the southeast in some places, toward the northwest in others. Several cross-faults and longitudinal faults have been located on the southeast flank of the anticline.

Most tectonic information is derived from the shallow formations. Little is known of the deeper parts of the structure which were reached by a few scattered

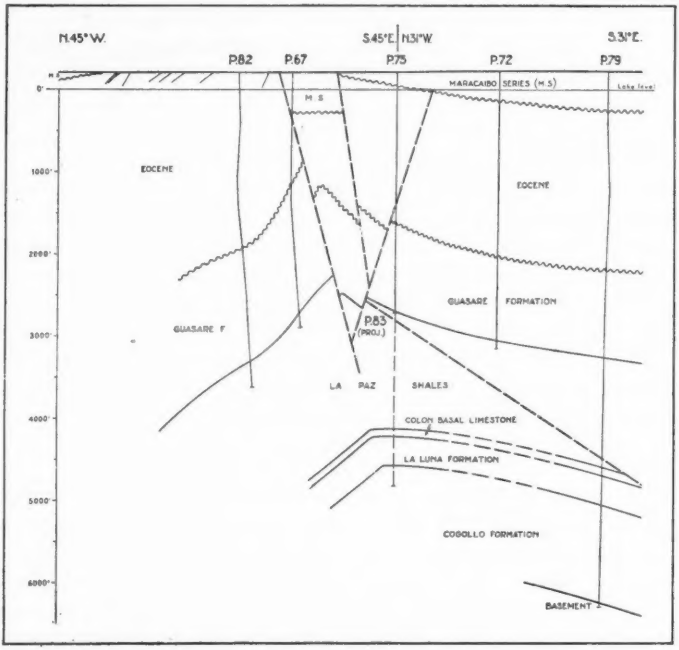


FIG. 22.—Cross section through La Paz field, according to G. Dickinson. Horizontal and vertical scales equal (see left margin).

wells only. It is quite possible that the anticline is less accentuated in the Lower Cretaceous formations than higher in the section.

OIL AND GAS RESERVOIRS

(Fig. 20)

The characteristics of the Eocene and the Guasare formations (shallow levels) as oil-producing formations have now been fairly well established, but those of the Lower Cretaceous formations (deep levels) are still a matter of speculation. In the shallow levels oil is produced from sands at the base of the Eocene and from sands throughout the Guasare formation. The higher Eocene sands are commonly water-bearing.

The accumulation in the shallow levels is essentially of the structural type but the unconformity between the Eocene and the Guasare formation and the lenticular sand development in both formations also influence it to a considerable extent.

The reservoir is open in the southern part of the field, where heavy oil seeps out and forms large asphalt deposits and where the water table is generally much higher than in the north. The oil produced near the seepages is the heaviest obtained in the field.

The available determinations indicate an average porosity of 26 per cent for the Upper sands (Eocene) and 22 per cent for the unconsolidated sands of the Guasare formation. Permeability in both formations is good, commonly as high as 500 millidarcys. Some of the calcareous sandstones in the Guasare formation, however, have low porosity and permeability. Both formations are usually produced together where the Eocene is oil-bearing.

Gravity of the oil varies from 29.3° to 12.9° A.P.I. (S.G. 0.88–0.98) and it has been possible to recognize areas which produce crudes of different gravity. Development during recent years was concentrated in light-oil areas. In general the Eocene appears to produce somewhat heavier oil than the Guasare formation, but heavy oil has also been obtained from the latter.

The oil obtained from the Lower Cretaceous formations has an average gravity of 33.6° A.P.I.(S.G. 0.857). Production comes from the Colón basal limestone, from the La Luna, and from the Cogollo formations. A considerable amount of study is still required to determine the characteristics of this reservoir.

DRILLING AND COMPLETION PRACTICE

Some of the wells aiming at production from the shallow levels have been drilled with a Franks portable outfit, but it was found preferable to use a steam rig for the deeper wells on the flanks of the structure. Depth varies from 2,000 to 4,000 feet. The average time for these wells during the present drilling campaign is about 1 month to 6 weeks. Wells drilled into the lower levels require much more time but experience is insufficient to determine average drilling time. Depth varied from 4,000 to 6,500 feet and these wells were drilled with steam rigs.

The completion practice for wells drilled into the shallow levels is to cement a $10\frac{3}{4}$-inch surface string at 200 feet and drill to final depth. It is then determined from the Schlumberger log which section is to be produced and a 7-inch water string is cemented at appropriate depth in order to shut off the water from higher sands. A $4\frac{1}{2}$-inch, 0.012-gauge wire-wrapped screen liner is hung with a Brown liner-hanger against the productive formation and washed into production. In the case of the lower section the practice, so far, has been to cement $13\frac{3}{8}$-inch or $10\frac{3}{4}$-inch casing at about 1,000 feet and drill into the top of the Colón limestones, where $9\frac{5}{8}$-inch or 7-inch casing is cemented. Wells are then drilled to final completion depth and brought into production from the open hole.

Considerable coring, ditch sampling, and wall sampling have been carried out in all formations, as correlation relies on micro-paleontological determination as well as on Schlumberger logging.

PRODUCTION

A total of 91 wells had been drilled in the La Paz field at the end of 1946. Forty-eight wells were actually producing (flowing 21, pumping 22, gas-lift 5), nine had been abandoned, and the remaining wells were either closed or idle for various reasons.

Initial production from the shallow levels in La Paz has ordinarily been

TABLE XXVI

PRODUCTION STATISTICS OF LA PAZ FIELD

ANNUAL PRODUCTION

Year	*Barrels*
1925	265,276
1926	751,470
1927	206,328
1928	15,392
1929	83,004
1930	336,186
1931	661,514
1932	402,919
1933	261,394
1934	227,107
1935	167,155
1936	173,816
1937	319,052
1938	832,583
1939	522,098
1940	449,232
1941	417,366
1942	309,750
1943	1,102,776
1944	3,642,348
1945	8,049,038
Total	19,195,804

PRODUCTION DURING DECEMBER, 1945

	Total Production (Barrels)	*Average Daily Production (Barrels)*	*Average Daily Potential (Barrels)*	*No. of Producing Wells*
Flowing		24,500	24,500	19
Pumping		2,470	2,470	40
Total	836,569	26,970	26,970	59

between 300 and 1,000 barrels, with a decline of around 2 per cent per month. However, due to the varied nature of the producing formations and the difference of the sands taken into production in different wells, results have been erratic and difficult to assess.

Initial production rates of the deeper levels also vary considerably and figures as low as 120 barrels per day have been observed. Probably a representative average is 5,000 barrels, but only a few wells have reached the deeper levels.

Production records of the La Paz field are given in Table XXVI; daily produc-

tion was 55,000 barrels at the end of 1946, of which 90 per cent was from the limestone. Analytical data on the La Paz oil are assembled in Table XXVII.

Gas-oil ratios are relatively low and amount to 600-850 cubic feet per barrel of oil for both shallow and deeper levels.

TABLE XXVII

CHARACTERISTICS OF LA PAZ CRUDE OIL

GENERAL	
Type	Asphaltic
Specific gravity range	0.850 to 0.980
A.P.I. gravity range	35°–12.9°
CRUDE OIL TAKEN FROM MAIN STORAGE, APRIL, 1945	
Specific gravity 60/60°	0.8717
A.P.I. gravity	30.8°
Color by reflected light	Black
Color by transmitted light	Dark brown
Viscosity Engler at 30°C.	2.26°
Viscosity Engler at 50°C.	1.62°
Flash point	Below 50°F.
Pour point test	Below 32°F.
Paraffine wax	1.77%
Setting point of paraffine wax	56°C.
Sulphur	1.7%
Initial boiling point	62°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING DECEMBER, 1945	
Yield by volume	
Gasoline	22.43%
Gas oil	26.45%
Fuel Oil	50.12%
Properties of products	
Gasoline	
Specific gravity at 60°F.	0.734
Distilling up to 100°C. (A.S.T.M.)	25%
F.B.P. (A.S.T.M.)	203°C.
Octane number (C.F.R. Motor method)	47
Gas oil	
Specific gravity at 60°F.	0.836
Distilling up to 300°C. (A.S.T.M.)	75½%
Sulphur content	0.74%
Diesel index	60.3
Fuel oil	
Specific gravity at 60°F.	0.945
Viscosity Redwood I at 100°F.	2,110 sec.

Of the gas produced about one million cubic feet per day is piped to Maracaibo for domestic supply in accordance with an agreement with the Venezuelan Government by which the Venezuelan Oil Concessions Limited deliver gas free of charge to the town. The installation of a gasoline absorption plant is planned for the near future.

TABLE XXVIII

ANALYSIS OF WATER FROM GUASARE FORMATION, LA PAZ FIELD

Field:	La Paz	Date sample collected:	May 8, 1945
Well No:	P-81	Date sample analyzed:	May 26, 1945
Depth:	3,270 feet		

Color: Colorless, clear
Odor: Of Petroleum acid soaps } after filtration
H_2S is not present
Free CO_2 is not present
Naphthenic acids were not determined
Total alkalinity is equivalent to 1,146 mgms. $CaCO_3$ per liter
Total hardness is equivalent to 159 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 159 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to Nil mgms. $CaCO_3$ per liter

MODIFIED REISTLE SYSTEM

Radical		*Milligrams Per Liter*	*Equivalent Values without Adjustment*
Sodium (incl. potassium)	Na′	5,999	260.82
Calcium	Ca″	34	1.70
Magnesium	Mg″	18	1.48
Positive sub-total			264.00
Chloride	Cl′	8,550	241.11
Sulphate	SO_4″	—	—
Carbonate	CO_3″	84	2.80
Hydrocarbonate	HCO_3″	1,226	20.09
Negative sub-total			264.00
Grand total		15,911	528.00

PALMER'S SYSTEM

Total reaction value in mgms. H per liter	528
Chloride salinity	100%
Primary salinity	91%
Primary alkalinity	8%
Secondary alkalinity	1%

Note: Sodium by difference
Interval open: 2,990–3,270 feet Guasare formation
Date: June 4, 1945 Laboratory San Lorenzo

Some water is produced with the oil obtained from the Eocene and the Guasare formations. This does not seem to be connected with a water drive, but apparently some sands of the producing section are water-logged and can not easily be excluded from production. An analysis of water from the Guasare formation is given in Table XXVIII.

The first pressure-bomb survey of the La Paz field was made early in 1944. Only the shallow levels were covered and pressures in this reservoir varied from 200 to 800 pounds per square inch at an average depth of 2,000 feet. The original pressure of the reservoir is unknown.

So far, the proved area of the La Paz field extends 6½ km. along the axis of the structure with a maximum width of 2 km. covering an area of about 1,500 acres. The limits of production in the deep levels have not been determined.

The field has been developed in recent years on a 400-meter square (approximately 40 acres) spacing plan as far as the shallow levels are concerned.

The oil is pumped from La Paz via La Concepción or Mara to the terminal at Palmarejo. It is sent from there by shallow draft tankers to Curaçao.

TABLE XXIX

CHARACTERISTICS OF TETONES CRUDE OIL

Specific gravity 60/60°F.	0.8846
A.P.I. gravity	28.5°
Color by reflected light	Black
Color by transmitted light	Dark brown
Viscosity Engler at 30°C.	3.07°
Viscosity Engler at 50°C.	2.01°
Flash point	Below 50°F.
Pour point test	Below 32°F.
Paraffine wax	2.30%
Setting point of paraffine wax	58°C.
Sulphur	2.07%
Initial boiling point	68°
Yields by volume	
Gasoline	21.4%
Gas oil	23.4%
Fuel oil	54.2%

TETONES FIELD (MARA)

The Tetones area is situated in the Mara District about 30 km. (18 miles) north of La Concepción (Fig. 1). A wildcat completed on this structure in 1945 found prolific production in the Cretaceous formations. This well was located on information obtained through surface geology, gravity, structure drilling, and seismic surveys. All these methods indicated the presence of a steeply folded anticline. By detailed reflection shooting sufficient information was obtained to contour the top of the Cretaceous and the resulting map is serving as a guide for further development.

By the end of 1945 two wells were drilling but only the discovery well was completed. It produced 28.9° A.P.I. gravity (S.G. 0.882) oil (Table XXIX) at the rate of 6,160 barrels daily. A pipe line of 28 km. (17 miles) and a loading terminal at Palmarejo north of Maracaibo were completed and also two oiled roads connecting Tetones with Palmarejo and with the Concepción field, from which Tetones is administered.

Production during December, 1945, was 186,059 barrels, and total production amounted to 1,140,466 barrels at the end of the year. The gas-oil ratio was approximately 560 cubic feet per barrel and about one third of the gas was used in operations. At the end of 1946, five wells were drilled and had a daily capacity of approximately 20,000 barrels.

Stratigraphical and tectonical conditions of Tetones are similar to those of La Paz. Very little is as yet known regarding the reservoir conditions and much further investigation and drilling will be required to obtain a clear picture of the extension of the reservoir and characteristics.

Part V. Tarra Field

Situation and development

The Manueles and Cruces fields of the Colón Development Company are situated on the so-called Tarra anticline in the Colón District, State of Zulia, at a distance of about 230 kilometers (143 miles) south and a little west of Maracaibo, and approximately 100 km. (62 miles) in a direct line from the southern extremity and nearest part of Lake Maracaibo (Fig. 1).

The fields are located on a narrow range of strongly dissected hills which are the morphological expression of the anticline. The terrane presents difficult problems for road building and selection of locations. Well elevations range from 170 to 700 feet above sea-level. The Tara and Zulia rivers flow at a distance on either side of the hills in low, partly swampy plains.

When exploration started in 1914 the whole area was covered with tropical forest and was uninhabited, excepting the hostile Motilone Indians. In the early days material was moved across Lake Maracaibo and on the Catatumbo River to two small river ports on the Tarra River. To-day a small railroad connects the little town of Encontrados with the Tarra fields. An airfield provides easy access to Casigua, the main camp for the area, and around the company's installations and camps several agricultural settlements have sprung up.

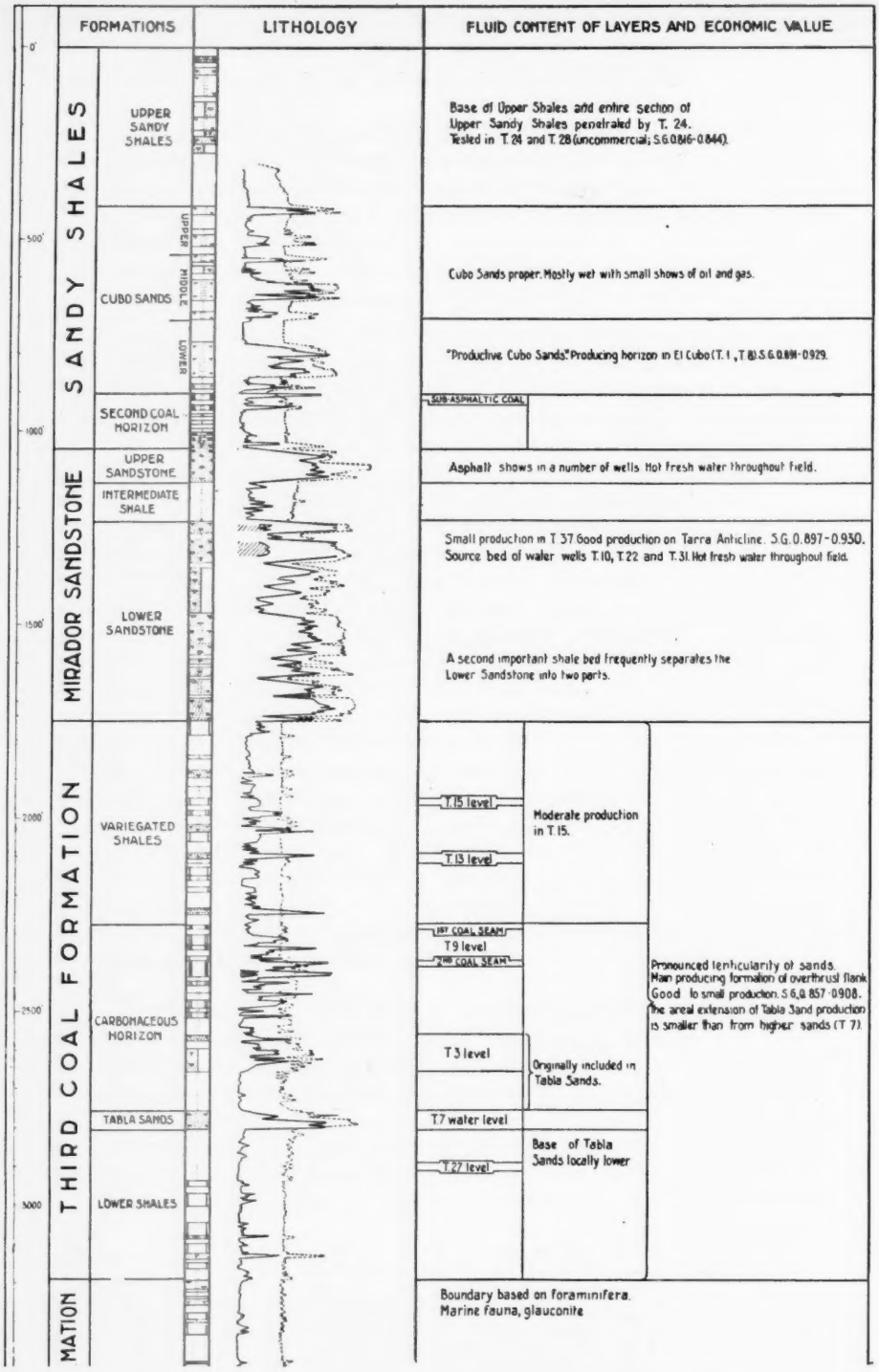
For the sake of completeness it may be mentioned that the Colón Development Company started drilling in the Colón District in 1914, on the Rio de Oro anticline (Fig. 1). Although oil was produced, exploration in this area was suspended after further drilling in 1925-1927. A total of four wells has been drilled in Rio de Oro.

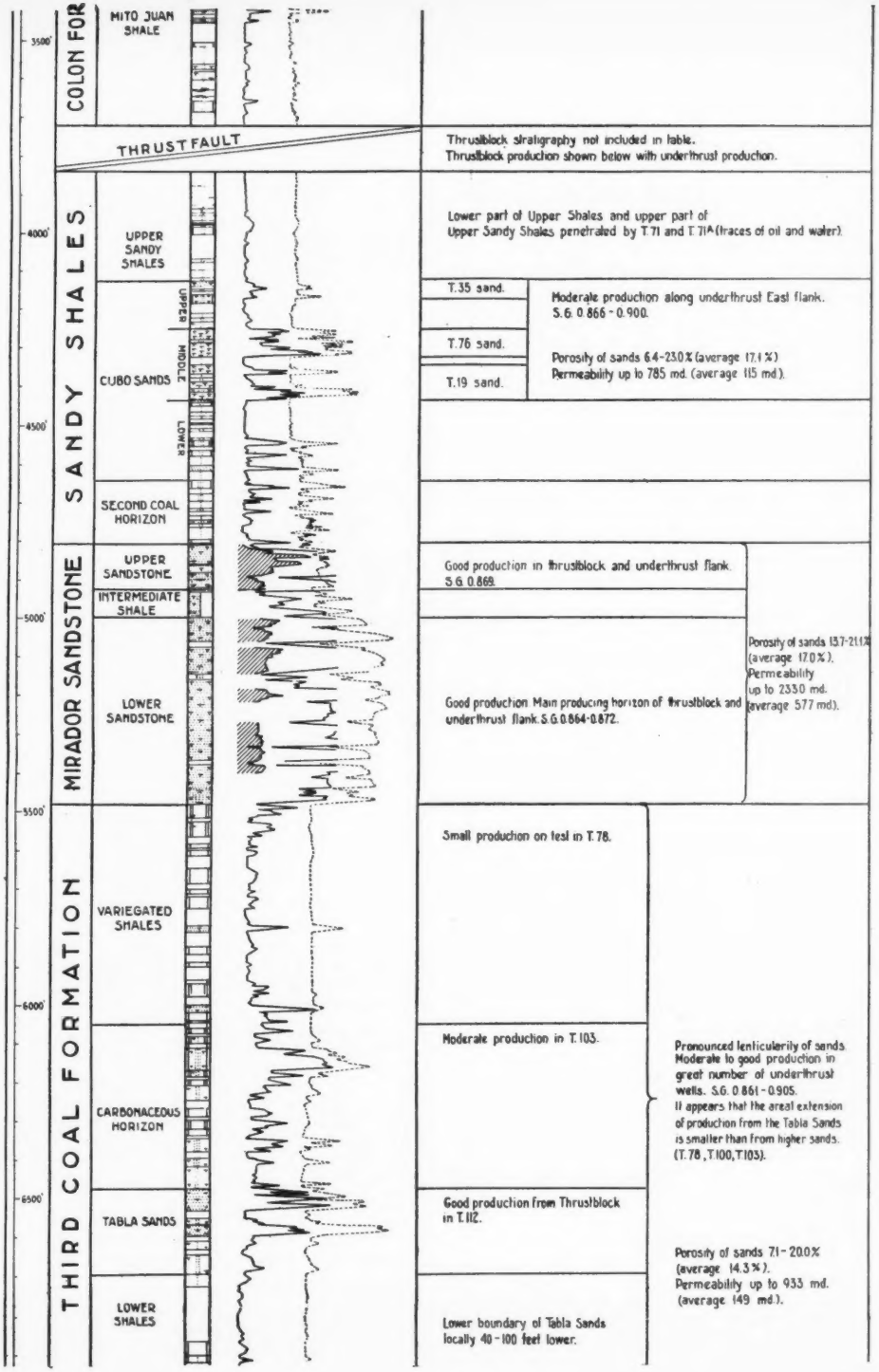
Drilling was commenced in the Cruces field in 1916 and in Los Manueles in 1926, but only after completion of the pipe line in 1930 was sustained production possible.

The fields were discovered as the result of geological investigations of the Tarra anticline where seepages are common. Considerable surface work has since been carried out from time to time when outstepping was being considered.

The Tarra fields are situated entirely in concessions held by the Colón Development Company. Las Cruces is about 25 km. (15.5 miles) north of the Petrólea field (Barco Concession, Republic of Colombia). An excellent paper on the geology of this neighboring area[21] has been published some years ago to which the reader interested in a regional study is referred.

[21] H. B. Notestein, C. W. Hubman, and J. H. Bowler, "Geology of the Barco Concession, Republic of Colombia, South America," *Bull. Geol. Soc. America*, Vol. 55 (1944).


FORMATIONS
LITHOLOGY
FLUID CONTENT OF LAYERS AND ECONOMIC VALUE
0'
500'
1000'
1500'
2000'
2500'
5000
SANDY SHALES
UPPER SANDY SHALES
CUBO SANDS
UPPER
MIDDLE
LOWER
SECOND COAL HORIZON
MIRADOR SANDSTONE
UPPER SANDSTONE
INTERMEDIATE SHALE
LOWER SANDSTONE
THIRD COAL FORMATION
VARIEGATED SHALES
CARBONACEOUS HORIZON
TABLA SANDS
LOWER SHALES
MATION
Base of Upper Shales and entire section of Upper Sandy Shales penetrated by T. 24. Tested in T. 24 and T. 28 (uncommercial; S.G. 0.846-0.844).
Cubo Sands proper. Mostly wet with small shows of oil and gas.
"Productive Cubo Sands". Producing horizon in El Cubo (T. 1, T. 8). S.G. 0.891-0.929.
SUB-ASPHALTIC COAL
Asphalt shows in a number of wells. Hot fresh water throughout field.
Small production in T. 37. Good production on Tarra Anticline. S.G. 0.897-0.930. Source bed of water wells T. 10, T. 22 and T. 31. Hot fresh water throughout field.
A second important shale bed frequently separates the Lower Sandstone into two parts.
T.15 level
T.13 level
Moderate production in T. 15.
1ST COAL SEAM
T.9 level
2ND COAL SEAM
Pronounced lenticularity of sands. Main producing formation of overthrust flank. Good to small production. S.G. 0.857-0.908. The areal extension of Tabla Sand production is smaller than from higher sands (T. 7).
T.3 level
Originally included in Tabla Sands.
T.7 water level
Base of Tabla Sands locally lower
T.27 level
Boundary based on foraminifera. Marine fauna, glauconite


3500'
4000'
4500'
5000'
5500'
6000'
6500'
COLON FOR
MITO JUAN SHALE
THRUST FAULT
SANDY SHALES
UPPER SANDY SHALES
CUBO SANDS
UPPER
MIDDLE
LOWER
SECOND COAL HORIZON
MIRADOR SANDSTONE
UPPER SANDSTONE
INTERMEDIATE SHALE
LOWER SANDSTONE
THIRD COAL FORMATION
VARIEGATED SHALES
CARBONACEOUS HORIZON
TABLA SANDS
LOWER SHALES
Thrustblock stratigraphy not included in table.
Thrustblock production shown below with underthrust production.
Lower part of Upper Shales and upper part of
Upper Sandy Shales penetrated by T.71 and T.71A (traces of oil and water).
T.35 sand.
T.76 sand.
T.19 sand.
Moderate production along underthrust East flank.
S.G. 0.866 - 0.900.
Porosity of sands 6.4-23.0 % (average 17.1 %)
Permeability up to 785 md. (average 115 md.).
Good production in thrustblock and underthrust flank.
S.G. 0.869.
Good production. Main producing horizon of thrustblock and underthrust flank. S.G. 0.864-0.872.
Porosity of sands 13.7-21.1 % (average 17.0 %).
Permeability up to 2330 md. (average 577 md.).
Small production on test in T.78.
Moderate production in T.103.
Pronounced lenticularity of sands.
Moderate to good production in great number of underthrust wells. S.G. 0.861 - 0.905.
It appears that the areal extension of production from the Tabla Sands is smaller than from higher sands. (T.78, T.100, T.103).
Good production from Thrustblock in T.112.
Porosity of sands 7.1 - 20.0 % (average 14.3 %).
Permeability up to 933 md. (average 149 md.).
Lower boundary of Tabla Sands locally 40 - 100 feet lower.

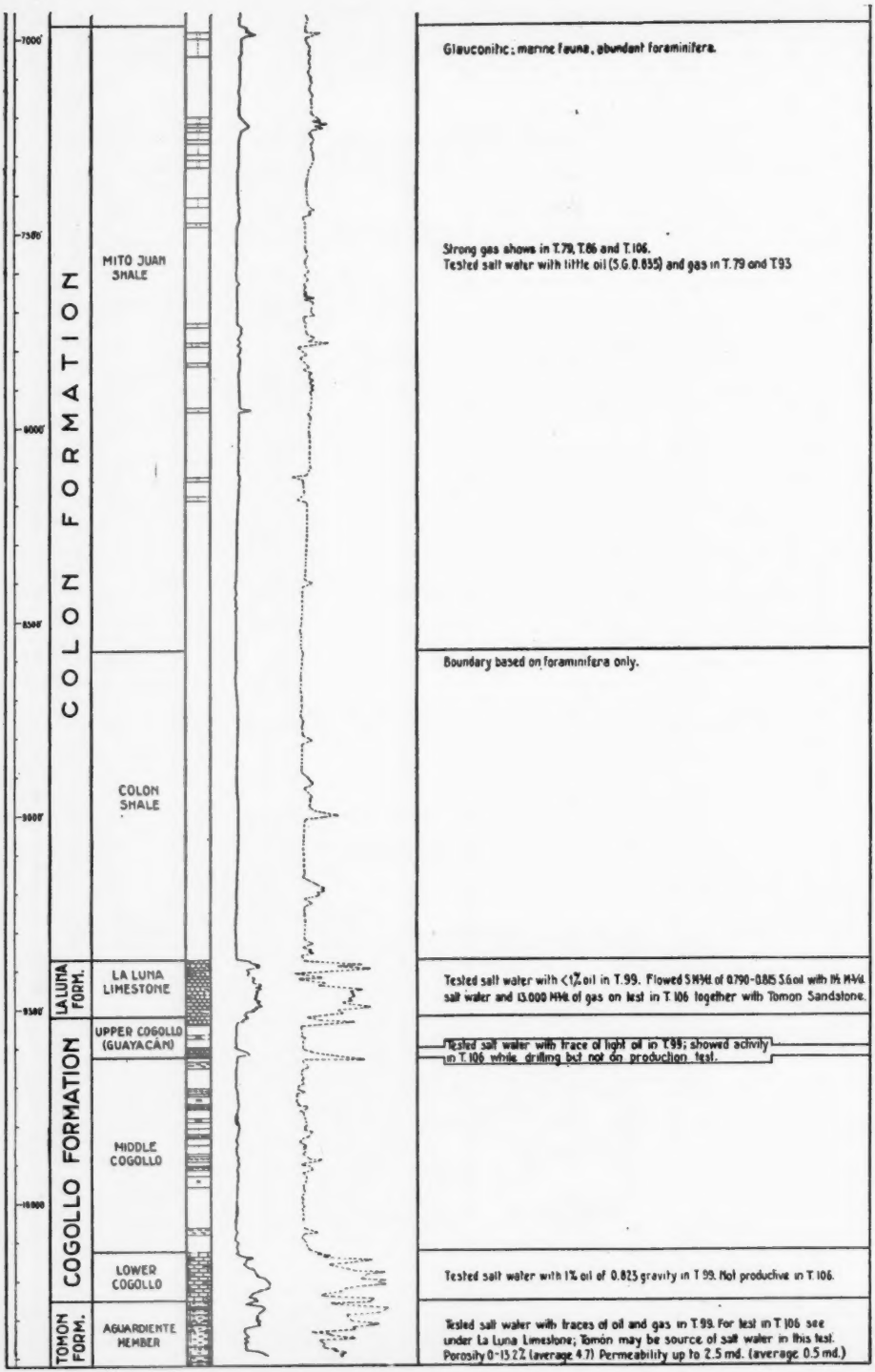

7000'
7500'
8000'
8500'
9000'
9500'
10000'
COLON FORMATION
COGOLLO FORMATION
LA LUNA FORM.
TOMON FORM.
MITO JUAN SHALE
COLON SHALE
LA LUNA LIMESTONE
UPPER COGOLLO (GUAYACAN)
MIDDLE COGOLLO
LOWER COGOLLO
AGUARDIENTE MEMBER
Glauconitic; marine fauna, abundant foraminifera.
Strong gas shows in T.79, T.86 and T.106.
Tested salt water with little oil (S.G. 0.835) and gas in T.79 and T.93
Boundary based on foraminifera only.
Tested salt water with <1% oil in T.99. Flowed 5 M³/d of 0.790-0.815 S.G. oil with 1% M³/d. salt water and 13.000 M³/d of gas on test in T.106 together with Tomon Sandstone.
Tested salt water with trace of light oil in T.99; showed activity in T.106 while drilling but not on production test.
Tested salt water with 1% oil of 0.823 gravity in T.99. Not productive in T.106.
Tested salt water with traces of oil and gas in T.99. For test in T.106 see under La Luna Limestone; Tomón may be source of salt water in this test. Porosity 0-13.2% (average 4.7) Permeability up to 2.5 md. (average 0.5 md.)

FIG. 23.—Type section of Las Cruces field.

STRATIGRAPHY

(Fig. 23)

The stratigraphical sequence present in the Tarra fields is subdivided from top to bottom as follows.

Upper, Lower Guayabo formation	Miocene-Pliocene
Upper Shales formation[22]	Oligocene
Sandy Shales formation[22]	Eocene-Oligocene
Mirador formation, Third Coal formation[22]	Eocene
Mito Juan formation, Colón formation	Maestrichtian-Coniacian
La Luna formation	Turonian-Cenomanian
Cogollo formation	Aptian-Albian
Tomón formation	Aptian and older
Unconformity	
Basement	Pre-Cretaceous

With the exception of the transgression at the base of the Cretaceous no unconformity has so far been definitely observed in the sequence of the Colón district, and it is thought that sedimentation was continuous from the Lower Cretaceous to the Miocene.[23]

PRE-CRETACEOUS

The basement has not yet been reached by any well in the Tarra fields. By analogy with the Barco Concession it is expected to consist of metamorphic rocks, perhaps with some intrusions.

CRETACEOUS

Tomón formation.—Only the top of this formation, which is the equivalent of the Uribante formation of the Barco Concession, has been reached in two wells. The uppermost beds consist of hard, fine- to medium-grained, micaceous sandstones with some quartz pebbles and shale streaks. There is a gradual transition to the Cogollo formation. Nothing is known of the thickness of the formation in the Tarra fields or of the development or presence of its lower members, which are productive in the Barco Concession. The formation is approximately 1,400 feet thick in the latter area.

[22] These formation names belong to a subdivision established in the early exploration of the Tarra region which included a First, Second, and Third Coal Horizon and several other names now used mainly for subsurface correlation. Though not very suitable these terms are so ingrained in the field vocabulary that it would be difficult to replace them. León and Carbonera formations are the equivalents of Upper shales and Sandy shales in the Barco Concession (see F. B. Notestein *et al.*, *op. cit.*), and F. A. Sutton ("Geology of Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10, 1946) introduced the name Angostura formation for the Third Coal Horizon. These names might be used to advantage in the Colón district.

[23] See F. B. Notestein *et al.*, *op. cit.*, and H. P. Schaub, "Outline of Sedimentation in Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 2 (February, 1948), pp. 215–27.

Cogollo formation.—The Cogollo formation was penetrated in two wells in the Cruces field (Fig. 25). It is composed mainly of shales with interbedded limestone beds, and resembles even in minor details the section known in the Barco Concession. The formation is only 900 feet thick, compared with 1,150 feet at La Paz and 1,370 feet at Tetones, where it is composed mainly of limestone.

La Luna formation.—The Luna formation consists of hard, black, very calcareous shales and dark gray limestones. It is only 150 feet thick compared with 330 feet in the La Paz field.

Colón formation.—The Colón formation consists of approximately 800 feet of hard, dark gray shales, which are slightly calcareous and contain a rich assemblage of foraminifera. A glauconitic horizon marks the base of the formation.

Mito Juan formation.—The Mito Juan consists of 1,680 feet of hard, gray, slightly sandy and micaceous shales. Fossil shells, ironstone nodules, and glauconite are common in the uppermost 300 feet, where a few thin layers of limestone and sandstone have been observed. The Colón shales grade into the Mito Juan shales, the contact being marked by a change in faunal content from the calcareous Colón fauna to the poorer, predominantly arenaceous Mito Juan fauna. The relation with the Third Coal formation is also transitional but the Third Coal contains no marine faunas.

The Mito Juan is the oldest formation exposed in the core of the Tarra anticline north of the Colombian boundary. The formation as defined here corresponds with the Mito Juan formation of the Barco Concession, but includes also the greater part of the so-called Catatumbo formation.

The boundary between Tertiary and Cretaceous is placed arbitrarily at the top of the Mito Juan. Cretaceous fossils have been found in this formation, and undoubtedly a good part of the Third Coal formation belongs to the Eocene and Paleocene, but it is not certain that the lithologic change between the two formations coincides exactly with the Cretaceous-Tertiary boundary.

TERTIARY

Third Coal formation.—The Third Coal formation consists of gray sandy shales, lenticular sandstone, carbonaceous shales with coal seams, and mottled shales. For subsurface correlations it is subdivided into four members, the most important being the so-called Tabla sands, an outstanding group of lenticular sandstones in the lower third of the formation.

The total thickness of the formation is about 1,500 feet. It can be correlated closely with the Barco and Los Cuervos formations described in the Barco Concession. Characteristics of the formation are irregular sedimentation and brackish facies. Its contact with the Mirador formation is transitional.

Mirador formation.—The Mirador formation is an excellent major key horizon for surface and subsurface mapping. Mainly composed of white, sugary sandstone, it forms outstanding strike ridges. A subdivision into an upper and lower Mirador sandstone is based on the presence of a shale body which is 70–90 feet thick. In

well T–106 the upper sandstone body (Mirador I) is 200 feet thick, the lower (Mirador II) 500 feet. The shale break consists of light gray sandy shales with one or two thin shaly coal seams. A quartz conglomerate, with pebbles reaching a diameter of 2 centimeters, commonly marks the top of the formation.

Although sand development in the Mirador is in places lenticular and subject to abrupt changes over short distances the facies of the formation as a whole is remarkably constant over a large area reaching from the northern boundary of the Colón District north of Rio de Oro to the Rubio Basin in the State of Tachira. The origin of the sand is unknown, but must perhaps be sought somewhere on the west, as the thickness of the formation decreases from west to east. In the Cruces field a reduction from 770 feet in well T–106 to 700 feet in the overthrust at Las Cruces, 660 feet in the underthrust (Fig. 25) and perhaps 600 feet in T–113 (Fig. 24 for location) can be observed.

Sandy Shales formation.—The Sandy Shales, which are the equivalent of the Carbonera formation in the Barco Concession, are composed mainly of sandy shales and sandstones. They are approximately 1,500 feet thick and subdivided into several members.

The Sandy Shales overlie the Mirador formation with a transition. About 140 feet above the top of the latter an outstanding cannel coal (the so-called "Subasphaltic Coal") occurs which is 3–10 feet thick, dull black and very light, with a peculiar conchoidal fracture. In many places it contains small pieces of fossil resin. It occurs on the Tarra anticline over a length of 35 km. (22 miles) from the Colombian boundary to the Manueles field and is a very good key bed both in wells and at the surface. It is overlain by the so-called Cubo sands, which are about 500 feet thick and consist of many, commonly crossbedded sandstone beds with intercalated sandy shales Several shaly coal seams occur in the uppermost member of Sandy Shales. The contact with the Upper Shales is transitional.

Upper Shales formation.—The Upper Shales formation is about 1,350 feet thick in Los Manueles. It consists almost exclusively of gray shales, which weather easily with a typical red color. Poor arenaceous foraminiferal faunas and fish remains occur in the formation. The Upper Shales are the equivalent of the León shales in the Barco Concession.

Guayabo formation.—The beginning of Guayabo time is characterized by a sudden influx of much sandy material. The contact with the Upper Shales is sharp, although no unconformity seems to be present. The Guayabo consists mainly of soft, loose, yellowish weathering sands and bluish sandy clays. Deposition was very irregular, cross-bedding is common and small intraformational unconformities and conglomerates can be observed in excavations. The formation is subdivided for the purpose of surface mapping into upper and lower Guayabo. Some thin, shaly coal seams characterize the upper Guayabo.

The thickness of the Guayabo formation is unknown. In Los Manueles, 1,500 feet were perforated , but the total thickness must amount to 10,000 feet and more in the deep synclinal area between the Tarra anticline and the Mérida Andes.

STRUCTURE
(Figs. 24–26)

GENERAL

The Tarra anticline is an outstanding fold striking northward into the southwestern lobe of the Maracaibo Basin approximately midway between the Perijá Range and the Mérida Andes. It is about 75 km. (46 miles) long at the surface but may continue under the alluvial plains north of Los Manueles. It develops from a group of anticlines which descend northward from the large Santiago dome, a high uplift situated northwest of Cucuta.[24]

The highest part of the Tarra anticlinorium is the so-called Petrólea South dome, about 18 km. (11 miles) south of the Colombian boundary. The anticline plunges in a northerly direction from this culmination, but local reversals of the plunge occur in at least three areas, namely in the Petrólea North dome (Petrólea field), in the Cruces dome (Las Cruces field) and in the Manueles dome (Los Manueles field).

A short description of the structural development of the Tarra anticline in Venezuela is necessary for an understanding of the complicated tectonics of the producing fields. Near the Colombian boundary the anticline is asymmetric, with a steep to overturned west flank and a gentle east flank. The latter is complicated by a thrust fault approximately 3 km. east of the axis, which shows a westerly thrust movement and determines the secondary Redondo structure, a continuation of the Carbonera thrust fold in Colombia.

About halfway between the Petrólea and Cruces fields the Tarra anticline is very narrow and steep, both flanks being nearly vertical. The Redondo thrust fold is here represented by a range of low hills east of the Tarra ridge, the so-called Guayabo hills.

Farther north (about 4 km. ($2\frac{1}{2}$ miles) south of Camp C, which is indicated in Figure 24), a thrust movement develops out of the core of the steep, highly compressed anticline. The west flank of the structure is pushed over the east flank and, furthermore, both flanks become much less inclined, giving the impression that the thrust relieves a strong pressure.

This so-called Tarra thrust has been mapped over a length of 23 km. (14 miles) to the Manueles field and may continue even farther north.

LAS CRUCES FIELD
(Fig. 25)

The Tarra thrust has strongly influenced accumulation in the Cruces field. Accordingly all tectonic units are named with reference to the Tarra thrust, namely,

Overthrust = the overthrust west flank
Underthrust = the east flank
Thrust block = a narrow drag wedge along the thrust plane.

[24] See map contained in paper by F. B. Notestein *et al.* (*op. cit.*).

The Las Cruces field was originally located on a flat, domal uplift in the Overthrust, which plunges north and south and has a closure of approximately 125 feet. It is 3.5 km. (2 miles) long and has a maximum width of 1.5 km. (1 mile). The deepest formation present in the Overthrust is the Mito Juan. Of importance for structural interpretation is a steep zone on the west flank, which indicates a steepening of the thrust fault. The Cruces dome is separated on the east by a shallow syncline (Las Cruces syncline) from a group of narrow anticlines along the thrust front. These so-called Agua Caliente anticlines have steep to overturned east flanks, and gentle west flanks. They extend from Camp C about 12 km. (7.5 miles) northward, that is, much farther north than the Cruces dome.

The thrust block (or blocks) is a thin wedge of steeply inclined, broken beds, which was dragged along the thrust plane. It is about 200 feet thick and has been observed over a distance of 8 km. (5 miles) along the thrust. It extends farther north than the Cruces dome.

The underthrust is the gently dipping east flank of the Tarra anticline. The presence of a deep-seated anticlinal core below the thrust is assumed but remains to be proved. A secondary, smaller thrust fault about 2,500 feet below the Tarra thrust is also assumed. A culmination probably exists in the underthrust beneath the Cruces dome.

The thrust plane dips about 15° west between the thrust front and the Cruces dome, but presumably steepens beneath the steep west flank of the dome. The total throw amounts to 1,500 meters (nearly one mile).

MANUELES FIELD

(Fig. 26)

The Manueles field is located on an axial culmination of the Tarra anticline about 15 km. north of the Cruces dome. Structural conditions are similar but less complicated. A very gentle west flank (10°) is thrust over an equally gentle east flank. The Tarra thrust has a hade of approximately 45° and the throw is about 700 meters (0.45 mile).

The closure of the overthrust dome amounts to 300 feet, its length to 3 km. (nearly 2 miles), and its width to 1 km. (0.6 mile).

OIL AND GAS RESERVOIR

(Fig. 23)

The following members of the stratigraphical sequence can be classed as actual or potential reservoirs of the Tarra field.

TOMÓN, COGOLLO, AND LA LUNA FORMATIONS

The Tomón, Cogollo, and La Luna formations are potential reservoirs in the Tarra fields. The La Luna, the Cogollo, and the uppermost part of the Tomón have been tested in two wells. Non-commercial quantities of light oil (S.G. 0.815, 45° A.P.I.) were obtained in one of them, while the other showed water. As

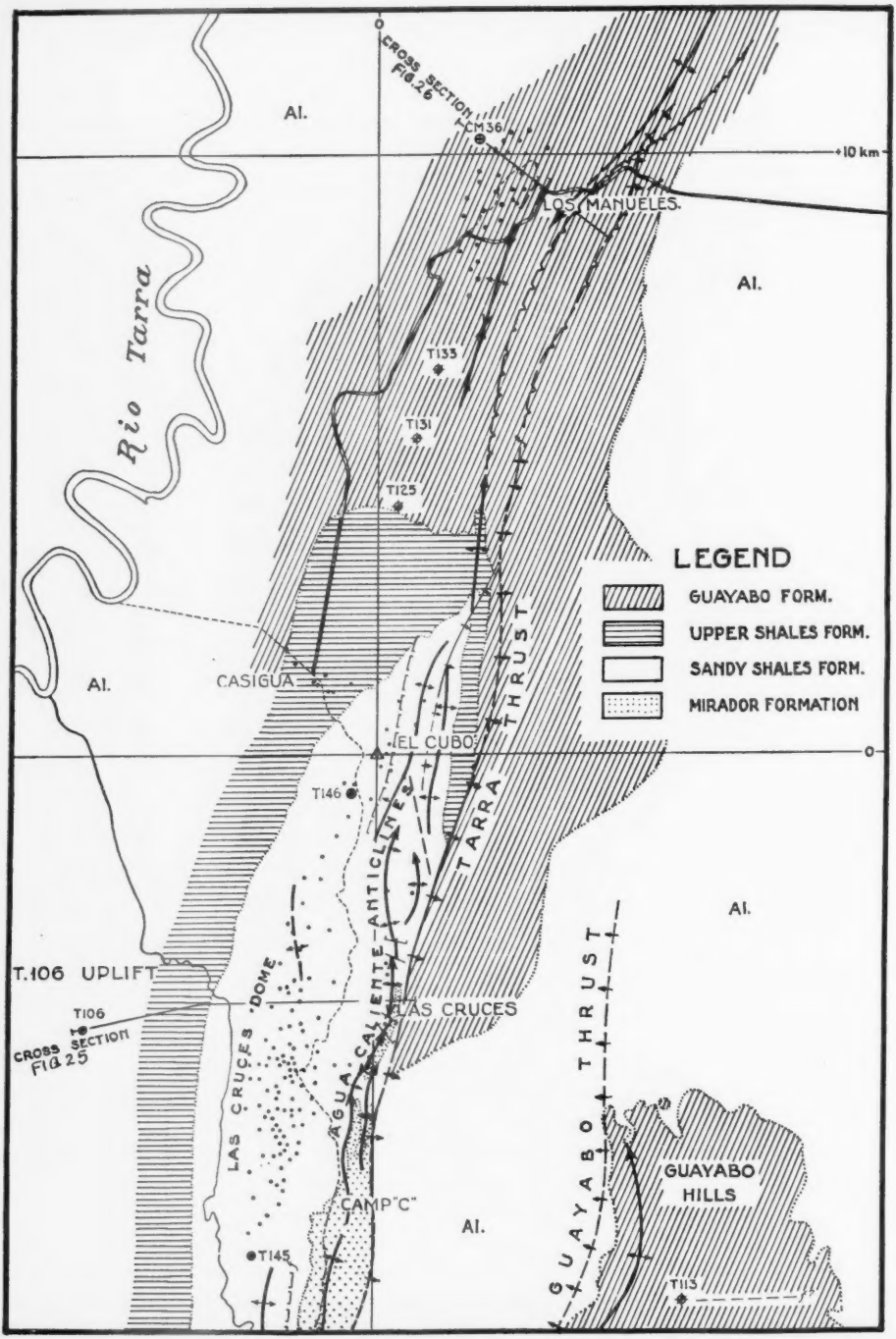


FIG. 24.—Geological map of Tarra fields. Al: Alluvium. Scale indicated by 10-kilometer grid.

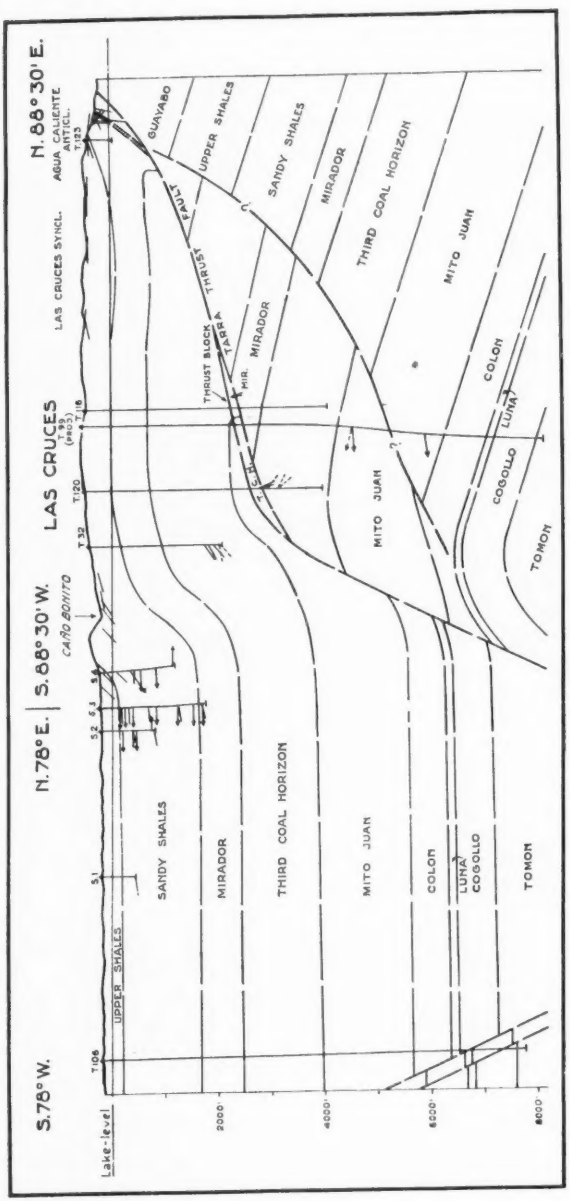


FIG. 23.—Cross section through Las Cruces field, according to R. Martin and H. P. Schaub.
Vertical and horizontal scale equal (see left margin)

these formations occur at great depth and as La Luna and Cogollo are probably not good reservoirs in view of their unfavorable facies, only the prospect of good production from the lower Tomón warrants the necessary deep tests.

THIRD COAL FORMATION

The Third Coal formation is productive in the Cruces field. The main oil zone

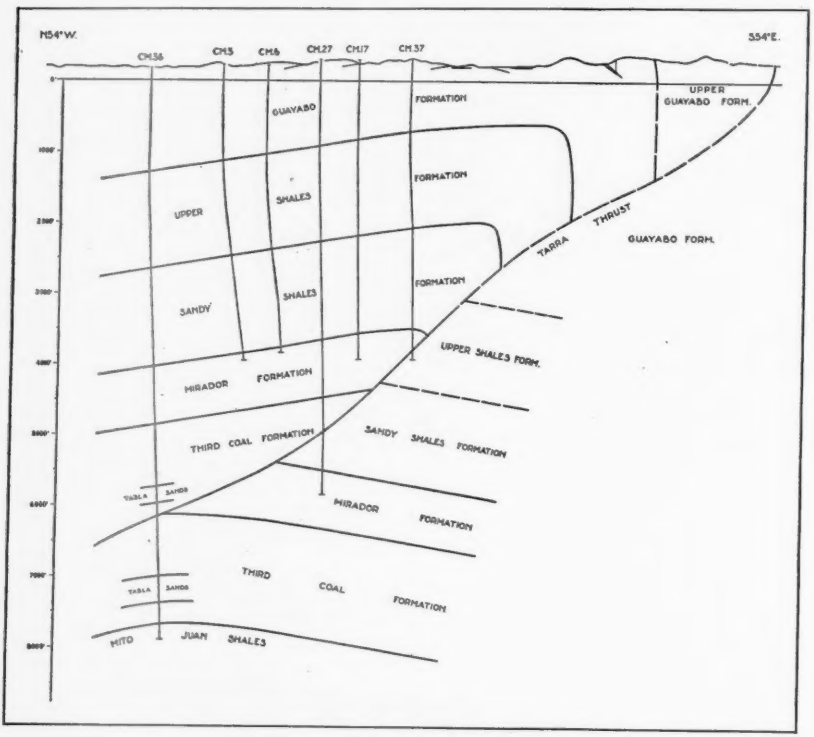


FIG. 26.—Cross section through Los Manueles field, according to G. Dickinson. Vertical and horizontal scale equal (see left margin).

is the Tabla sands, but moderate amounts of oil can be obtained also from higher sands.

Porosity of the Tabla sands is commonly between 8 and 10 per cent but may be as high as 20 per cent in the thrust block. Permeability is mostly very low, with the exception of the thrust block, where high values were observed.

The oil obtained from this formation ranges in gravity from 34.8° to 24.3° A.P.I. (S.G. 0.857—0.908). Average sand thickness is 60 feet over a proved productive area of 1,500 acres in the underthrust; 400 acres in the overthrust.

However, the limits of the productive area are not yet properly established. Good amounts of oil are produced from the Tabla sands in the thrust block but this is a very narrow zone in view of the steep dip.

Pronounced lenticularity of these sands seems to affect production throughout the Cruces field.

MIRADOR FORMATION

The Mirador formation is the main producing formation in the Manueles field. It is also exploited in Las Cruces in the underthrust, in the thrust block and on the Agua Caliente anticlines where shallow production was recently discovered.

The average porosity of the Mirador sandstones is 18 per cent, the average permeability 600 millidarcys.

The formation is divided into two reservoirs by the shale break. The productive area is approximately 300 acres in Los Manueles, and 75 acres in the Cruces field, excluding the Agua Caliente anticlines.

The Mirador oil ranges in gravity from 32.5° to 27.5° A.P.I. (S.G. 0.863-0.890) in Los Manueles, from 32.3° to 30.8° A.P.I. (S.G. 0.864-0.872) in the Cruces underthrust and from 32.5° to 18.1° A.P.I. (S.G. 0.863-0.946) in the overthrust and the Agua Caliente anticlines.

The Mirador sandstone contains fresh hot water (salinity 10–60 milligrams of chlorine per liter) in the Tarra region, wherever it is not oil-bearing. Many hot springs with an average temperature of 60° are known (hence, the name Agua Caliente). Mirador water is produced from two wells in the Cruces field and serves for operations and domestic use (Table XXX).

SANDY SHALES FORMATION

The Sandy Shales formation is productive in Los Manueles and Las Cruces. Oil in Los Manueles is produced from sands in the lower half of the formation and has a gravity of 38.2° A.P.I. (S.G. 0.834). The sands have a porosity of 20 per cent, a permeability up to 250 millidarcys.

In Las Cruces a good volume of oil with an average gravity of 25.7 A.P.I. (S.G. 0.90) was found in the overthrust during the early days of exploration, about 5 km. (3 miles) north of the Cruces dome. The accumulation conditions in this area, which was originally called El Cubo field, are not yet well understood, but appear to be locally restricted. Some Sandy Shales oil is also produced from the Cruces underthrust and thrust block. It has a gravity of about 31.1° A.P.I. (S.G. 0.87). The Cubo sands have an average porosity of 16 per cent, a permeability of 5 to 40 millidarcys.

RESERVOIR CONDITIONS

Production characteristics show clearly that the Mirador formation of the Manueles field produces by a strong water drive. In the Mirador I a small gas cap has been observed.

In the Las Cruces field conditions are rather complex. The Mirador formation

of the Cruces dome, Agua Caliente, and part of the thrust block produces by water drive; the Third Coal formation produces probably by dissolved gas drive in the underthrust and possibly also in the overthrust.

DRILLING AND COMPLETION PRACTICE

At present two types of wells are being drilled in the Cruces field, namely, shallow wells on the Agua Caliente structures, for Mirador production, and wells

TABLE XXX

ANALYSIS OF MIRADOR WATER FROM LAS CRUCES FIELD

Field:	Las Cruces	Producing formation:	Lower Mirador
Well No.:	T-22	Depth:	886–1,388 feet, open 1,040–1,060 feet
Depth:	2,482 feet	Method of sampling:	Boiler

Color: Clear, color less
Taste: None
Odor: Very slightly of petroleum acid soaps } After filtration
H_2S is not present
Free CO_2 is present and is 7 mgm. per liter
Total hardness is equivalent to 43 mgms. $CaCO_3$ per liter
Temporary hardness is equivalent to 43 mgms. $CaCO_3$ per liter
Permanent hardness is equivalent to nil mgms. $CaCO_3$ per liter

The water contains the following in mgms. per liter

Sodium (incl. potassium)	Na'	64
Calcium	Ca''	12
Magnesium	Mg''	3
Chloride	Cl'	26
Sulphate	SO_4''	20
Carbonate	CO_3''	0
Hydrocarbonate	HCO_3'	178
Silica	SiO_2	20
Iron and aluminum oxides		0.8

The following gives a hypothetical combination of the radicals in mgms. per liter

Calcium bicarbonate	$Ca(HCO_3)_2$	49
Magnesium bicarbonate	$Mg(HCO_3)_2$	18
Sodium bicarbonate	$Na(HCO_3)$	173
Sodium chloride	NaCl	43
Silica	SiO_2	20
Iron and aluminum oxides	$Al_2O_3+Fe_2O_3$	0.8

This water is suitable as a domestic supply after sedimentation and filtration
Remarks: Well produces approximately 2,000 cubic meters per day of hot water by gas lift. The water is used for domestic supply in the Cruces field

Laboratory San Lorenzo

of medium depth drilled into the thrust block or the underthrust Third Coal formation. No exploitation drilling is being carried out in Los Manueles, but a semi-exploration well has been completed in 1945.

The shallow holes in Agua Caliente, ranging from 600 to 1,000 feet in depth, are drilled with a Franks portable outfit at an average of three per month. The wells are completed with 80 feet of $8\frac{5}{8}$-inch surface casing and with $5\frac{3}{4}$-inch casing

cemented through the producing zone. Twin wells are now drilled to Mirador I and II separately, and in general the casing is gun-perforated opposite intervals of these sandstones selected on the Schlumberger log. Cores are taken for determination of fluid content, porosity, and permeability.

The deeper Third Coal formation wells reach an average depth of 5,000 feet and are drilled with steam rigs in about 2 months. They are completed with an $8\frac{5}{8}$-inch surface string cemented at the base of the water-bearing overthrust Mirador at 1,500–2,000 feet, and a $4\frac{1}{2}$-inch combination string cemented above the Tabla sands, with $\frac{3}{8}$-inch perforations opposite sand intervals selected from the Schlumberger log.

In general correlation is based on electrical logs, which give satisfactory results in undisturbed areas, but are difficult to interpret in faulted sections. Deviation and self-potential dip-meter surveys are made regularly.

PRODUCTION

A total of 166 wells had been drilled in the Cruces field at the end of 1945, including some outlying wildcats. Ninety wells were producing (21 flowing, 69 pumping), 20 had been abandoned, and the remaining wells were not producing for various reasons.

In Los Manueles, a total of 38 wells had been drilled, of which 19 were producing, 13 flowing, 6 pumping, and 3 had been abandoned. The remaining wells were not producing for various reasons (repairs, high gas-oil ratio).

The initial production results in Los Manueles Mirador wells were high and wells with initial production of 4,000 barrels per day were completed even in the latest stages of development. Influx of water, however, was rapid and many wells had only a short life before it was necessary to recomplete them in other sands because of excessive water production.

Initial production from the Third Coal formation in Las Cruces ranged from 600–800 barrels on $\frac{1}{2}$-inch bean from the thrust block to about 500 barrels on $\frac{1}{2}$-inch bean from the underthrust; the Mirador wells of Agua Caliente give an average of about 600 barrels on $\frac{1}{2}$-inch bean. Initial decline is everywhere fairly rapid. Daily potential production at the end of 1945 was 12,300 barrels for Las Cruces, 4,800 barrels for Los Manueles. Both fields were produced to capacity. Production statistics are given in Table XXXI and analytical data on the Tarra oils have been assembled in Table XXXII.

Average gas-oil ratio is approximately 750 cubic feet per barrel in Los Manueles and 350 cubic feet per barrel in Las Cruces. The gas production during December, 1945, amounted to 4,330,000 cubic feet in Los Manueles. About a third of the gas was used for operations.

Extensive dehydration facilities are required in both fields. In the early days dehydration was accomplished by chemical means. Electrical dehydration was introduced in recent years and sufficient Petreco units have been installed to dehydrate the entire wet production.

TABLE XXXI

PRODUCTION STATISTICS OF TARRA FIELD

ANNUAL PRODUCTION

Year	Las Cruces (Barrels)	Los Manueles (Barrels)
1922	7,000	
1923	8,000	
1924	10,000	
1925	20,000	
1926	40,000	
1927	70,000	
1928	100,000	
1929	303,687	498
1930	4,632,078	296,824
1931	4,339,094	3,116,999
1932	3,218,075	2,914,054
1933	3,193,730	3,726,889
1934	3,643,762	1,682,464
1935	3,948,038	1,183,646
1936	3,707,924	905,447
1937	3,129,488	1,097,013
1938	3,858,093	1,329,379
1939	3,934,083	1,708,383
1940	3,584,359	2,612,510
1941	2,998,919	3,650,204
1942	2,456,996[1]	3,075,255[1]
1943	3,765,040	3,500,390
1944	3,988,651	3,088,399
1945	3,873,367	1,933,283
Grand total	58,830,384	35,821,637

[1] Partly closed in because of shipping situation

PRODUCTION DURING DECEMBER, 1945

	Las Cruces			Los Manueles		
	Daily Average (Barrels)	Daily Potential (Barrels)	Number of Producing Wells	Daily Average (Barrels)	Daily Potential (Barrels)	Number of Producing Wells
Flowing	6,240	6,240	21	3,680	3,680	12
Pumping	6,080	6,080	64	1,120	1,120	5
Total	12,320	12,320	85	4,800	4,800	17
Total production	382,370				148,464	

A bottom-hole-pressure survey was made in the Los Manueles field in 1941 covering seven wells. Pressure at 3,900 feet subsea was practically the same in all these wells, and averaged within narrow limits approximately 1,860 pounds per square inch. In view of the strong water-drive characteristics of the field, it is probable that this pressure is not much lower than the original reservoir pressure.

A bottom-hole-pressure survey was carried out in 1942 in 13 wells of the Las Cruces field. At that time the pressure at the top of the underthrust Tabla sands ranged from 830 to 1,622 pounds per square inch at depths varying between 4,000 and 4,500 feet.

TABLE XXXII

CHARACTERISTUCS OF TARRA CRUDE OIL

	Los Manueles	*Las Cruces*
GENERAL		
Type	Mixed base	Mixed base
Specific gravity range	0.856–0.886	0.841–0.946
A.P.I. gravity range	33.8°–28.2	36.2–18.1
CRUDE OIL TAKEN FROM MAIN STORAGE ON APRIL 25, 1945		
Specific gravity 60/60°F.	0.8630	0.8802
A.P.I. gravity	32.5°	29.2°
Color by reflected light	Black	Black
Color by transmitted light	Dark brown	Dark brown
Viscosity Engler at 30°C.	2.16°	3.09°
Viscosity Engler at 50°C.	1.64°	1.97°
Flash point	Below 50°F.	Below 50°F.
Pour point test	Below 32°F.	Below 32°F.
Paraffine wax	3.08%	2.12%
Setting point of paraffine wax	58°C.	57°C.
Sulphur	0.80%	1.03%
Initial boiling point	58°C.	67°C.
CRUDE OIL RECEIVED IN CURAÇAO DURING OCTOBER, 1945 (MIXED LOS MANUELES, LAS CRUCES CRUDE)		
Yields by volume		
Gasoline	18.98%	
Gas oil	27.83%	
Fuel Oil	52.19%	
Properties of products		
Gasoline		
Specific gravity at 60°F.	0.731	
Distilling up to 100°C. (A.S.T.M.)	26%	
F.B.P. (A.S.T.M.)	200°C.	
Octane number (C.F.R. motor method)	49	
Gas oil		
Specific gravity at 60°F.	0.830	
Distilling up to 300°C. (A.S.T.M.)	74½%	
Sulphur content	0.33%	
Diesel index	64.3	
Fuel oil		
Specific gravity at 60°F.	0.945	
Viscosity Redwood I at 100°F.	3,360 sec.	

The proved areas of the fields are 1,000 hectares (2,500 acres) for Las Cruces, and 170 hectares (400 acres) for Los Manueles. Wells were drilled on an average 300-meter triangular spacing scheme (19 acres) in Los Manueles, but the hilly terrane, made it impossible to keep closely to a regular pattern. The spacing generally used in the Las Cruces field is 400 meters, but a regular pattern can not be followed on account of the many tectonic units, which are exploited separately.

The oil produced in the Tarra fields is shipped to Curaçao for refining. An 8-inch pipe line with two intermediate pump stations connects the Casigua main storage with the pipe line terminal at La Solita on the Escalante River (Fig. 1).

The tankers are loaded from a platform built on piles several kilometers from shore.

A small topping plant of 600 barrels daily capacity in Casigua and two weathering plants of 180 barrels daily capacity each, which are located at the pump stations along the pipe line, supply the local requirements of gasoline, kerosene, gas oil, and fuel oil.

Part VI. Conclusion: Origin and Accumulation of Oil in Maracaibo Basin

At the end of 1945 the eleven fields described in the preceding pages had produced a total of 1,181 million barrels and had still a daily potential of 250,750 barrels. In order to appreciate fully the importance of the Maracaibo Basin as an oil province, we have to add the production obtained by the Mene Grande Oil Company and the Creole Petroleum Corporation in their lake concessions, and the figures of some small, partly abandoned fields. The fields of the Colombian Petroleum Corporation situated in the Colombian part of the Maracaibo Basin must be mentioned also. We then arrive at the following approximate figures for the oil production of the Maracaibo Basin at the end of 1945.

Total production, 2,634.5 million barrels
Average daily production, 684,950 barrels, during week ending December 31, 1945

In concluding the present paper, a few considerations are given regarding the origin of the oil in the Maracaibo Basin. In some instances it seems possible to establish with little doubt whether the oil found in a particular formation is indigenous to it or has migrated into it, but more often only some suggestions can be made.

Oil accumulations in the Cretaceous are mostly connected with zoögenic limestones, part of which are bituminous. The La Luma formation, which consists mainly of bituminous, slaty limestones, has been described as an oil mother rock by H. D. Hedberg.[25] Hedberg thought that the Cogollo formation, which is composed mainly of light gray, massive fossiliferous limestone, has not the characteristics of a petroleum source rock and that most of the oil found in it has probably migrated there from another source. These conclusions should be reconsidered in the light of the prolific production from the Cogoleo in La Paz. Although there is no proof that all the oil stored in this formation is indigenous, and part of it may come from the La Luna along fault zones, it seems improbable that no oil should have been formed *in situ* since the Cogollo contains so many fossils in this area that much of it can be called a zoögenic formation.

There is no doubt that the oil found in the Cretaceous limestones (Cogollo, La Luna, and Basal Colón formation) at La Paz is indigenous to them as a whole.

[25] H. D. Hedberg, "Cretaceous Limestone as Petroleum Source Rock in Northwestern Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (1931).

As these limestones rest on igenous and metamorphic rocks, the oil could not have come from deeper formations. There is no reason to assume a migration from younger beds, for instance, due to overthrusting, because the oil in the limestone reservoir is different from that found in higher formations. The same argument is valid for Tetones and for some of the Cretaceous production in the Barco Concession. In both areas the producing formations are underlain by metamorphic rocks.

The thick shale complex in the Upper Cretaceous (Colón-Mito Juan shales, La Paz shales) is also suspected as a source series on account of its rich content of foraminifera. Thin sandstone beds intercalated in the shales are oil-impregnated wherever they occur, but if much oil has formed in this part of the sequence, it has migrated to better reservoirs. Thus, some of the oil recovered from Eocene sands (for instance, Third Coal formation of the Colón District) may come from the Upper Cretaceous shales.

On the other hand, most Eocene formations seem to contain enough organic matter to be the source of considerable quantities of oil. This applies first of all to the thick sequences of marine shales present in the eastern half of the Maracaibo Basin. The oil collected either in sandstones intercalated in the shales (Middle Paují sandstone at Mene Grande) or may have migrated into the Miocene. The example of Mene Grande, described in detail on page 567, seems to be good proof that oil was formed in the Eocene after the Miocene transgression and migrated updip against the unconformity. A similar origin is probable for much of the Eocene oil trapped beneath the Miocene unconformity in other parts of the Bolivar District and the lake area.

Even predominantly sandy formations of Eocene age ordinarily contain much shale and shaly sandstone with enough organic matter to warrant the assumption that some oil may have formed in them. An exception is the Mirador sandstone of the Colón District, which is composed of white, sugary, poorly cemented sandstones and seems to be practically barren of organic remains with the exception of some shaly coal seams intercalated in the so-called shale break. In slightly faulted uplifts the formation has so far been found without exception to be water-bearing, but fair oil accumulations occur in it on the Tarra anticline. This oil has probably migrated into the Mirador formation along the thrust zones.

By far the largest oil accumulations of western Venezuela which have so far been exploited have been found in the Miocene. It is very interesting to note that this oil always occurs close above the unconformity between Miocene and Eocene. In areas where the Miocene is not transgressive, no oil has so far been found in it (for example, the Colón District). Yet in certain areas of near-by Tachira, where similar beds are locally transgressive on Cretaceous, the basal conglomerates are saturated with heavy oil. Most of the Miocene formations do not give the impression of oil source beds, as they consist mainly of mottled clays and sands. Exceptions are the marine intercalations in the La Rosa and Lagunillas formations of the Bolivar District. On the whole, it seems that much of the oil found in the

Miocene is not indigenous but comes from the Eocene, which over large areas does not contain good reservoirs as it is mostly composed of shales, sandy shales, and quartzitic sandstones. In these areas oil forming in the Eocene would naturally migrate into the good reservoir of Miocene sands just above. On the other hand, where good reservoir sands are found in the Eocene below the unconformity, much oil also accumulates there.

Oil accumulation in the Maracaibo Basin is rarely governed by tectonic conditions alone, but rather by a combination of stratigraphic and structural trapping. As examples of the structural type of accumulation can be cited the Tarra fields, La Paz and La Concepción, but even there such stratigraphical conditions as lenticularity of sands influence the accumulation. In the Mene Grande field the two causes are about evenly balanced, while in the Bolivar Coast fields stratigraphic conditions seem to be more important than tectonic conditions.

Only in the case of the middle Paují accumulation in Mene Grande can an approximate age be indicated. Lower age limits are, of course, given by the age of the beds containing the oil, but, as the tectonic features controlling accumulations belong mainly to the Andean orogeny, it is probable that most accumulation took place during and after this event. Earlier accumulation was, however, possible in the Eocene of Mene Grande, Pueblo Viejo, and the Cretaceous of La Paz, since the presence of uplifts before the Andean folding must be assumed in these areas.

In the case of the Bolivar Coast fields and of Mene Grande, migration of oil from the Eocene into the Miocene may have started during the deposition of the Miocene sands, when a protection of the reservoir by overlying beds was still lacking. This would explain why the oil of the Bolivar Coast fields in general is heavy, especially in Tia Juana, where all light components are practically absent, although to-day the reservoir is not open. The light components may have escaped before sufficient overburden was formed. In Mene Grande a fossil seepage zone seems to be present at the base of the upper younger Tertiary along the Main Fault zone. This indicates that accumulation had already taken place when erosion set in after the first phase of the Andean folding.

It is estimated that 93 per cent of the mentioned total production has been derived from the Miocene, 6 per cent from the Eocene, and only about 1 per cent from the Cretaceous. This proportion has changed considerably in recent years and although most of the oil is still produced from the Miocene, it is estimated that current production from the Eocene has increased to 15–20 per cent, and from the Cretaceous to 6 per cent. This reflects the fact that the big Miocene accumulations are at shallow depths and were found early during the search for oil, while Eocene and Cretaceous exploration needs deeper drilling and has only been undertaken with some exceptions, in the last few years.

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MISSISSIPPIAN MARSHALL FORMATION OF MICHIGAN[1]

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ABSTRACT

The stratigraphy of the Marshall formation should not be studied as an independent unit. The underlying Coldwater shale can be divided into an eastern sandy facies and a western dolomitic facies. The sandy facies is inseparable from the Marshall formation at most places. Redbeds occur in both the Marshall formation and the upper Coldwater sediments in eastern Michigan. They are unreliable as stratigraphic markers except in local areas.

Neither color nor grain size provides a suitable basis for a division of the Marshall into two members throughout the Michigan basin. The coarse-grained Napoleon sandstone (upper Marshall) is a mappable unit in parts of eastern Michigan but loses its identity westward.

The top of the Marshall grades into the overlying Michigan formation. The Michigan "Stray" sandstones are the result of an interfingering of the Marshall and Michigan deposits and should not be considered to be entirely of Michigan age. In addition to the recognized eastern source of sediments for the Marshall formation, a western source is apparent.

INTRODUCTION

Objectives.—This report presents the results of a lithologic study of the Marshall formation of Michigan. Primary problems associated with the study were (1) the stratigraphic relationship of the Marshall formation to the underlying Coldwater shale, (2) the distribution of Mississippian redbeds and their value as stratigraphic markers, (3) the value of a division of the Marshall formation into two distinct members, and (4) the stratigraphic relationship of the Marshall formation to the overlying Michigan formation with particular regard to the Michigan "Stray" sandstone.

Stratigraphic position and areal distribution.—The stratigraphic relationship of the Marshall formation of lower Mississippian age to other formations in Michigan is shown in Figure 1. Marshall beds everywhere rest on the Coldwater formation and at most places are overlain by the clastic and chemically precipitated deposits of the Michigan formation. On the flanks of the Howell anticline in Livingston County and on at least two of the anticlines in the southeastern part of Bay County Marshall strata are overlain unconformably by Pennsylvanian rocks. The Marshall has been completely removed from the tops of these folds and Pennsylvanian rocks or glacial drift rest directly on the Coldwater shale.

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The writer is indebted to Professor K. K. Landes, chairman of the department of geology, University of Michigan, and to G. V. Cohee, United States Geological Survey, for outlining the problem and for the many hours they spent in directing the study to its completion. Many constructive suggestions and corrections also were made by Professor G. M. Ehlers and Professor A. J. Eardley, geology department, University of Michigan. Appreciation is expressed to Professor W. F. Hunt, chairman of the department of mineralogy, University of Michigan, for his aid in the petrographic work.

The field work was accomplished with finances and transportation furnished by the Michigan Department of Conservation, Geological Survey Division. Miss Helen M. Martin and other members of the Michigan Geological Survey staff have been most cooperative.

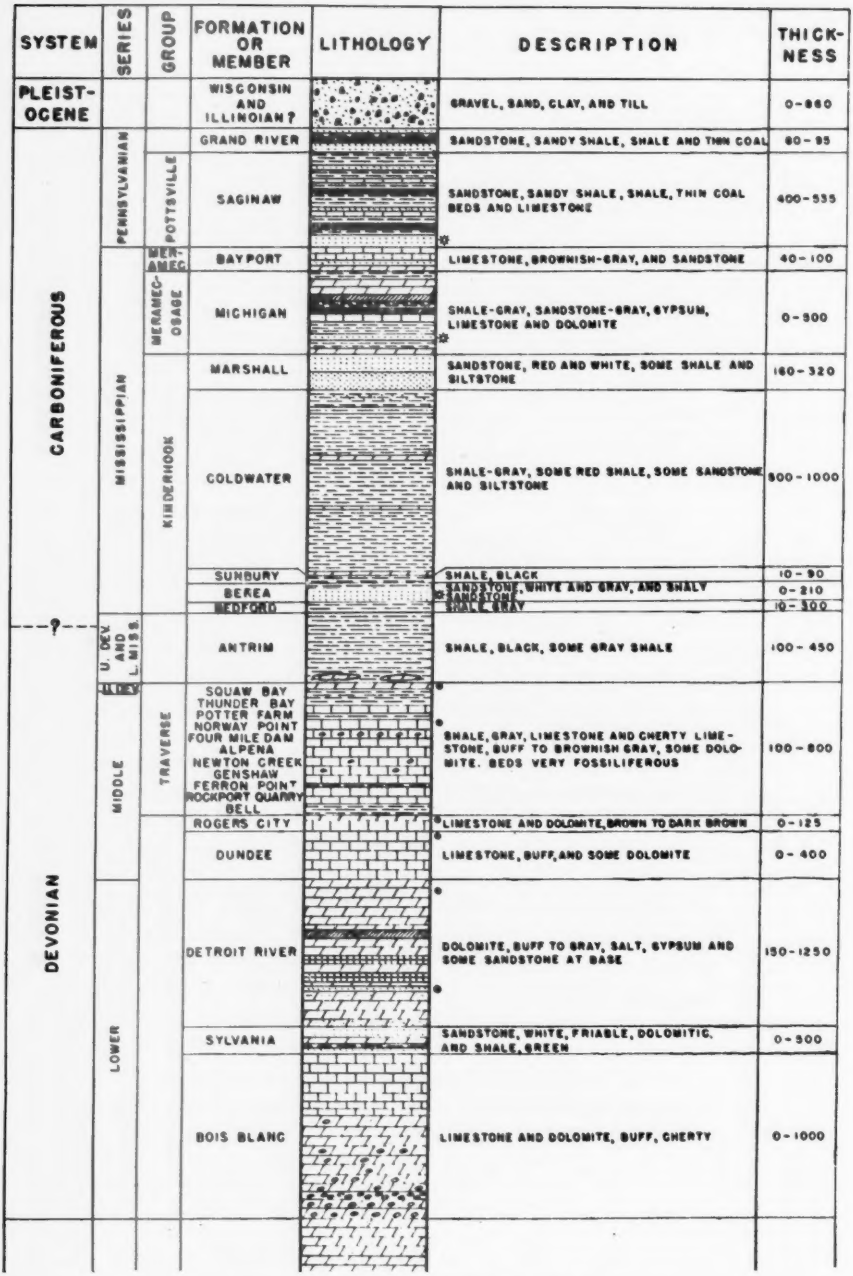


FIG. 1.—Generalized stratigraphic section of Carboniferous and Devonian for Southern Peninsula of Michigan.

The Marshall formation is confined to the gentle structural basin in the Southern Peninsula of Michigan. It directly underlies the glacial drift of the state in a circular outcrop zone characteristic of formations in the Michigan basin (Fig. 2). The width of the drift-covered outcrop area ranges from 3 to 20 miles. Exposures are limited to Jackson, Hillsdale, and Calhoun counties in southern Michigan, Ottawa County in southwestern Michigan, and Huron, Tuscola, and Sanilac counties in the "Thumb" area of eastern Michigan. The structural basin causes the Marshall formation to occur at increasing depths from the outcrop area toward Clare and Midland counties in the center of the state, where it is more than 1,500 feet below the surface.

The circular pattern of the drift-covered Marshall outcrop is interrupted appreciably in only two areas in the state. Erosion of the Marshal formation from the crest of the Howell anticline in Livingston and Shiawassee counties has extended the outcrop northward in a narrow and poorly defined band along the west and north flank of the structure. Marshall and Coldwater beds directly underlie the glacial drift on the anticlines in Ogemaw and Arenac counties. Well data which have become available since the publication of the geologic map of Michigan (Martin, 1936) indicate that the northern drift-covered outcrops of the Marshall and Coldwater formations swing southward and are continuous with the outcrops of the anticlines in Ogemaw and Arenac counties (Fig. 2).

In the eastern part of the state the contact of the Marshall with the Coldwater formation is indefinite, and in many places indeterminate, due to the presence of fine-grained sandstones and redbeds in the Coldwater. This problem is discussed under the description of the Coldwater formation, but is mentioned here to explain the absence of the Marshall-Coldwater contact line in eastern Michigan in Figure 2.

The outcrop pattern of the Marshall formation in Figure 2 is taken from the geologic map of Michigan (Martin, 1936) with changes in areas where additional information has become available since the publication of the map.

Nature of study.—Most of the information obtained in the study is from subsurface data. Drill cuttings from more than 1,000 wells in the state were examined microscopically. In addition to the examination of well samples, frequent use was made of thousands of driller's logs of wells in Michigan from which samples are not available. These logs were used extensively in the compilation of the structure-contour map (Fig. 19) on the base of the Coldwater shale because this is a stratigraphic marker which is easily recognized by drillers.

Cross sections.—As the upper and lower contacts of the Marshall formation are indefinite in many parts of the state, the best method of illustrating the occurrence of the formation is by cross sections. Six sections aid in presenting and discussing the character of the Coldwater-Marshall interval. In order to illustrate lateral lithologic changes more clearly, these sections were drawn with the well columns aligned on a stratigraphic datum rather than on sea-level. A second section showing the same wells based on sea-level datum is included. Lithologic character and details of correlation are omitted on the structure section.

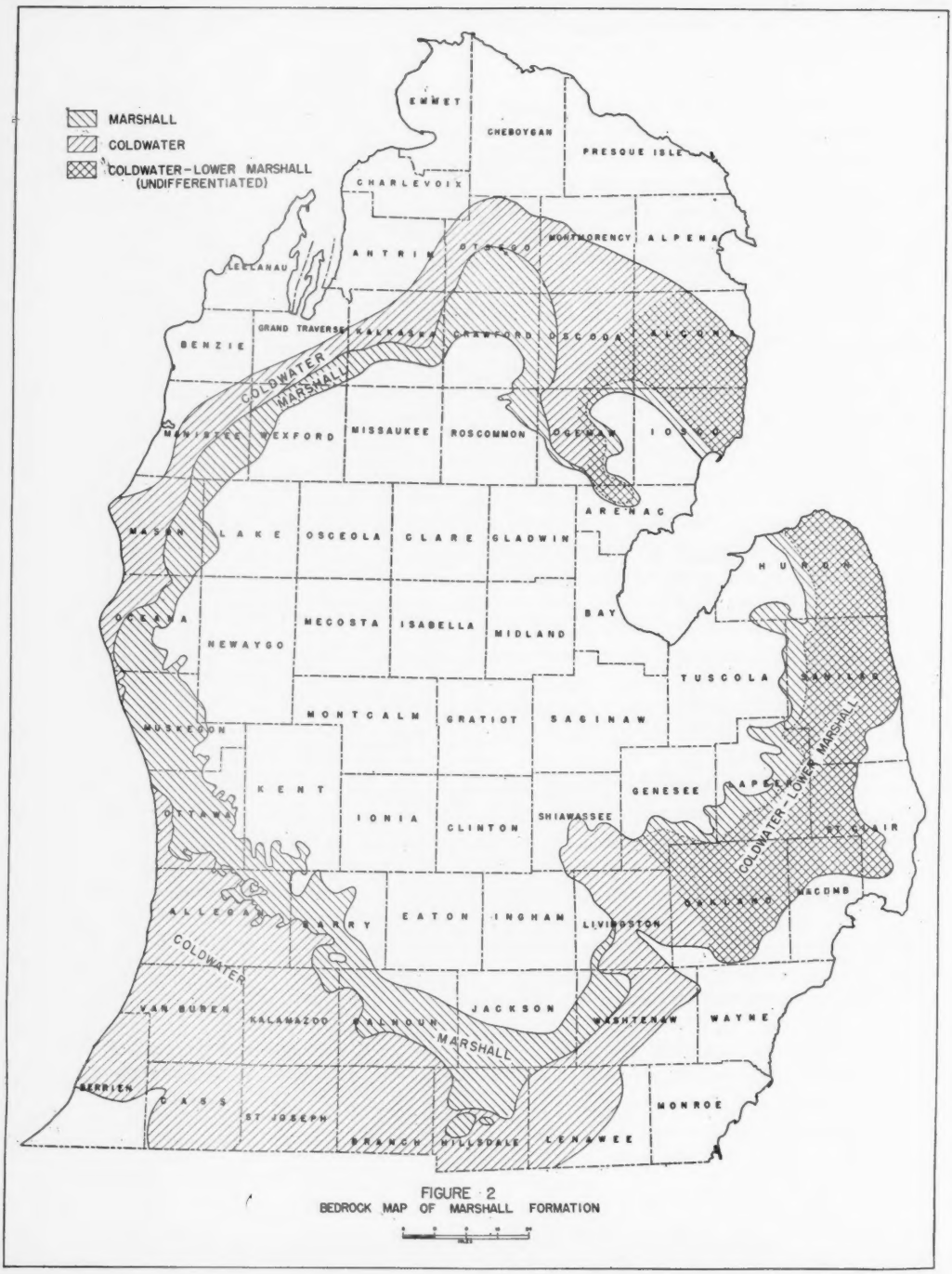


FIGURE 2
BEDROCK MAP OF MARSHALL FORMATION

FIG. 2.—Bedrock map of Marshall formation.

All lithologic description shown on the cross sections is determined from well-sample examinations made by the writer with only two exceptions. The lithologic description of well 18 in cross section *BB'* (Fig. 6) is plotted from a written description of the well samples published by the Geological Survey of Michigan. Well 6 in cross section *CC'* (Fig. 7) is plotted from a copy of the driller's log. Lithologic generalizations illustrated in the cross section are avoided where possible, but because of the small vertical scale, it is necessary to generalize the lithologic character of beds having a thickness of less than 10 feet.

Samples of the Coldwater formation are missing in many wells. In a few wells it is necessary to determine the base of the Coldwater from driller's logs supplied by the Geological Survey of Michigan.

The stratigraphic column (Fig. 1) is a reproduction of part of one recently compiled by George V. Cohee of the Ann Arbor, Michigan, office of the United States Geological Survey.

PREVIOUS WORK

Prior to the naming of the Marshall formation by Alexander Winchell in 1861, several geologists described some of the strata which later were assigned to the formation. Douglas Houghton (1838, p. 283) first State geologist of Michigan, referred to the sandstones at Pointe aux Barques as belonging to the "Lower Sandstone or Graywack Group" in his first annual report on the geology of Michigan. Houghton (1838, p. 279) also gave a brief account of the sandstone quarries at Jonesville and Napoleon, Michigan. A year later, Houghton (1839, p. 400) stated that the sandstones in Calhoun County belonged to "the great carboniferous group of rocks."

The first attempt at a systematic account of the strata which included part of the Marshall formation was made by Bela Hubbard in 1840. The following year, Hubbard (1841, p. 553) presented a stratigraphic column of the rocks cropping out in the "organized counties of Michigan." Winchell (1869, p. 59) wrote of this work: "In his attempt to assign them to their proper stratigraphical position, Mr. Hubbard fell into singular errors, and introduced into the most elaborate account of the lower peninsula which was destined to be published for twenty years, a confusion of facts which rendered the geology of Michigan an enigma to every one who attempted to parallelize the rocks with those of surrounding States."

The only other geologist who wrote concerning beds of the Marshall formation before the advent of the Winchell papers was R. P. Stevens (1858, p. 262), who described five species of fossils from the beds at Battle Creek. Stevens assigned these strata to the Carboniferous.

Three years later the first of a series of discussions of the Marshall formation by Alexander Winchell was published. Winchell (1861, p. 84) briefly described 25 feet of reddish to reddish green, fossiliferous sandstones cropping out near the town of Marshall in Calhoun County and named these beds in the Marshall group, stating that they were Chemung in age. He was able to trace the strata

northeastward into Huron County and northwestward into Ottawa County. Winchell (1861, p. 89) designated the grayer, less firmly cemented sandstone overlying the Marshall group as the Napoleon group and placed the latter at the base of the Carboniferous system. In regard to the Napoleon group, he (Winchell, 1861, p. 90) stated that, "As a distinct formation, therefore, it has no satisfactory equivalent in surrounding States; and there is no reason, except its negative paleontological characters, for separating it from the Marshall Group."

Winchell was the recognized authority on these beds for 15 years, although some of his ideas on the age of beds in other states which he correlated with his Marshall group were considered to be wrong by James Hall (Winchell, 1869, p. 73).

In his second report on the Marshall, Winchell (1862a, p. 353), after examining fossils from the top of the "Huron group," lowered the base of the "Marshall group" to include the 14 feet of bluish gritstone in the vicinity of Pointe aux Barques.

After the publication of this report, Winchell devoted his efforts to a study of the paleontology and age of the "Marshall group" and of its supposed equivalents in other states (Winchell, 1862a, 1862b, 1863). He abandoned his Chemung classification in 1865 and expressed the opinion that there was a "hitherto unrecognized group of strata lying at the very base of the carboniferous system" which is represented by the "carboniferous conglomerate" of western New York (Winchell, 1865, p. 110). He suggested that the westward extension of these conglomerates included the Marshall group.

Four years later a comprehensive summary of the work done on the Marshall group and its "equivalents" was presented by Winchell in a paper which was divided into two parts for publication (Winchell, 1869 and 1870). He (Winchell, 1870, p. 415) concluded that this group was equivalent to the upper part of the Catskill group of New York. He (Winchell, 1869, p. 74) again altered the stratigraphic table by making the "Napoleon group" a member of the "Marshall group" and by dividing the Marshall into three members with a total thickness of 298 feet as follows.

Marshall Group	*Feet*
Napoleon sandstone	123
Marshall sandstone	160
Huron gritstone	15

Although Winchell consistently referred to the strata under consideration as the "Marshall group," no publications subsequent to those of Winchell's were found in which the term "group" is used with the Marshall. The term "Marshall sandstone" was employed by Lane in 1895 and had the most frequent usuage until 1931. Since 1931 the term Marshall formation has been used in most publications.

Carl Rominger, who succeeded Winchell as State geologist of Michigan, discussed the Marshall rocks in his report on the Lower Peninsula (1876), but re-

fused to follow Winchell's nomenclature or classification of the beds. He referred to the strata as the "Waverly group" and included the present Coldwater in the group. He (Rominger, 1876, p. 98) described the sediments as being shore deposits and stated that, "The stratification often becomes discordant, and frequent changes in the material are induced by local influences; while in one place a shale bed forms, in another near by a sand-rock ledge may be accumulated. A comparison of the strata in different outcrops of the Waverly group will for these reasons rarely allow of an identification of certain beds, and often not even of their exact horizon in the series."

Later, however, Lane (1895, p. 19) concurred with Winchell's ideas and considered the Marshall as marking the time at which the geological history of Michigan became independent of that of adjacent states, "so that any parallel must be made paleontologically rather than stratigraphically."

Lane (1900), in his report on Huron County, began the present practice of separating the Marshall into two divisions, the lower Marshall and upper Marshall, and of making the term Napoleon synonymous with upper Marshall. He (Lane, 1900, p. 19) assigned a total thickness of 560 feet to the Marshall formation in Huron County and stated that the 260 feet of lower Marshall is a transition from the thick shale underlying the Marshall to the heavy sandstones of the Napoleon. Cooper (1906, pp. 154–55) agreed with this idea but wrote that in Bay County the lower Marshall is appreciably thicker and the upper Marshall much thinner than in Huron County.

Later, Lane and Seaman (1909, p. 82) described a westward thinning of the Marshall and explained it by earlier emergence in the southwestern part of the state than in the northeastern part.

In his report on Arenac County, Gregory (1912, p. 58) accounted for the upper Marshall sandstone as being deposited in a southward-retreating and open Paleozoic sea.

The first attempt at describing the history of Marshall time was made by Cook (1914 p. 64) in his discussion of the salt and brine deposits of Michigan. The main feature of this geologic history was the isolation of the Michigan basin during Marshall time. Cook suggested that the red shales of lower Marshall are seaward phases of the sandstones of upper Marshall.

In the same year, Smith (1914a) wrote the first comprehensive discussion of the possible oil and gas fields of Michigan. He (Smith, 1914a, p. 30) expressed the opinion that the lower Marshall sandstones of Huron County are replaced by sandy shales in the central part of the Michigan basin and that the bottom and top of the lower Marshall beds are generally marked by a red color.

The publication of Smith's report marked the end of what might be referred to as the first phase of publications concerning the Marshall formation. There followed a period of 15 years during which the Marshall is scarcely mentioned in geologic publications. Much information from subsurface studies was obtained during this period, and in 1929 the beginning of the recent series of discussions

regarding the subsurface character of the Marshall formation appeared. Problems of interest to the petroleum geologists such as key horizons within the Marshall and the nature of the upper and lower limits of the formation were the primary subjects.

Newcombe (1929, p. 207) started these discussions by stating that the red zones of lower Marshall exhibited no uniformity in the Saginaw oil field and were useless in that area as a mapping datum, but that the Napoleon sandstone had statewide value as a good correlation marker. Four years later, however, he (Newcombe, 1933, p. 82) wrote that the top of the Napoleon was eroded. According to Newcombe, this erosion gave rise to considerable surface relief and locally the entire formation may have been removed in the western part of the Michigan basin.

Publications following Newcombe's initial article are numerous and by many authors. The facts and ideas set forth in the publications are an integral part of the present conceptions of the stratigraphy of the Marshall formation and are discussed later in this report.

COLDWATER FORMATION

GENERAL FEATURES

The Coldwater formation consists of the gray and gray-blue shales underlying the Marshall formation in all parts of the Southern Peninsula of Michigan. At most places it rests on the black shale of the Sunbury formation, but at some localities, especially in western and southwestern Michigan, it directly overlies the Ellsworth green shale or the Antrim black shale.

Although division of the formation into smaller stratigraphic units in certain areas may be possible, no zones have been found which can be recognized in all parts of the state. However, the character of the Coldwater sediments changes noticeably from east to west. Two general types of Coldwater sediments are evident in Michigan: a western facies, consisting of 565–1,080 feet of shale, in many places calcareous, with some interbedded dolomites; and an eastern facies, characterized by siltstones and fine-grained sandstones interbedded with the shales. Red shales and siltstones are common in the upper sediments of the eastern facies. Gray shale is the predominant rock of the formation in all parts of Michigan with the exception of the extreme eastern edge, where sandstone and siltstone comprise the greater part of the section. More than 1,000 feet of gray shale with no distinctive lithologic changes are penetrated in some wells near the center of the state.

A redbed at the base of the Coldwater is the only zone within the formation that can be recognized in both the western and the eastern facies. This bed varies in thickness from a few inches to 40 feet. It is red dolomite or limestone on the west side of the state, especially in Oceana, Newaygo, and Muskegon counties, and red shale in Clinton, Saginaw, and Shiawassee counties and parts of adjacent counties in the eastern part of the state. At most places the bed occurs at the very

base of the Coldwater, but it may be as much as 30 feet or more above the base of the formation in some localities. The approximate areal distribution of these basal Coldwater red sediments, where they are continuous, is indicated in Figure 3. As the red zone is irregular in its occurrence in the northern part of the Southern Peninsula, no attempt is made to map its distribution in this area. Small isolated areas of it in Isabella, Midland, and Gladwin counties are not shown in Figure 3.

Overlying the basal red zone is a thick shale which is often described by drillers as "blue shale." The shale is gray, very fine-textured rock which may be bluish gray when wet. The thickness of this shale and the lithologic character of the sediments interbedded with the shale vary in different areas.

WESTERN FACIES

The Coldwater of the western half of the Southern Peninsula, here referred to as the western facies, contains several calcareous or dolomitic strata. Distinctive beds of dolomite are recognized in well cuttings at depths ranging from 150 to 750 feet above the base of the formation. Under the popular term "Coldwater lime," Hale (1941, p. 722) describes four types of dolomite occurring in the formation: (1) a speckled dolomite consisting of a gray dolomite matrix with embedded grains of light brown dolomite; (2) speckled dolomite with "pepperings" of glauconite; (3) crystalline dolomite with "pepperings" of glauconite; and (4) crystalline dolomite with no glauconite. By means of a map, she shows that the speckled dolomite and glauconitic dolomite are generally confined to the western margin counties of the state. She (Hale, 1941, p. 723) states, "Eastward the dolomite is crystalline rather than speckled, although it occurs at about the same horizon and contains a little glauconite. Farther east and especially north the crystalline zones are common throughout the Coldwater gray shale section and indicate no definite horizon." In addition to the crystalline dolomite, shaly dolomite and dolomitic shale are present in the Coldwater near the center of the state. Although the thicknesses and stratigraphic positions of the various dolomites differ greatly, the dolomites are concentrated near the center or in the upper part of the formation. Fossil fragments are common in these dolomites.

Lithologically, the upper Coldwater shales in the western half of the state are identical with the lower shales of the formation. The top of the Coldwater formation is relatively easy to determine because the lithologic difference between the gray Coldwater shale and the Marshall red and tan sandstones is marked.

The lateral change from the western dolomitic sediments to the eastern silty and sandy deposits is gradational. The siltstone beds nearest the western facies sediments are commonly very dolomitic. It is possible, however, to draw a line separating the general area in which definite siltstones are recognized from the general area in which non-silty dolomitic sediments are present (Fig. 3). This demarcation between the eastern and western facies coincides approximately with a 1,050-foot isopach line of the Coldwater. Although the thickness of the

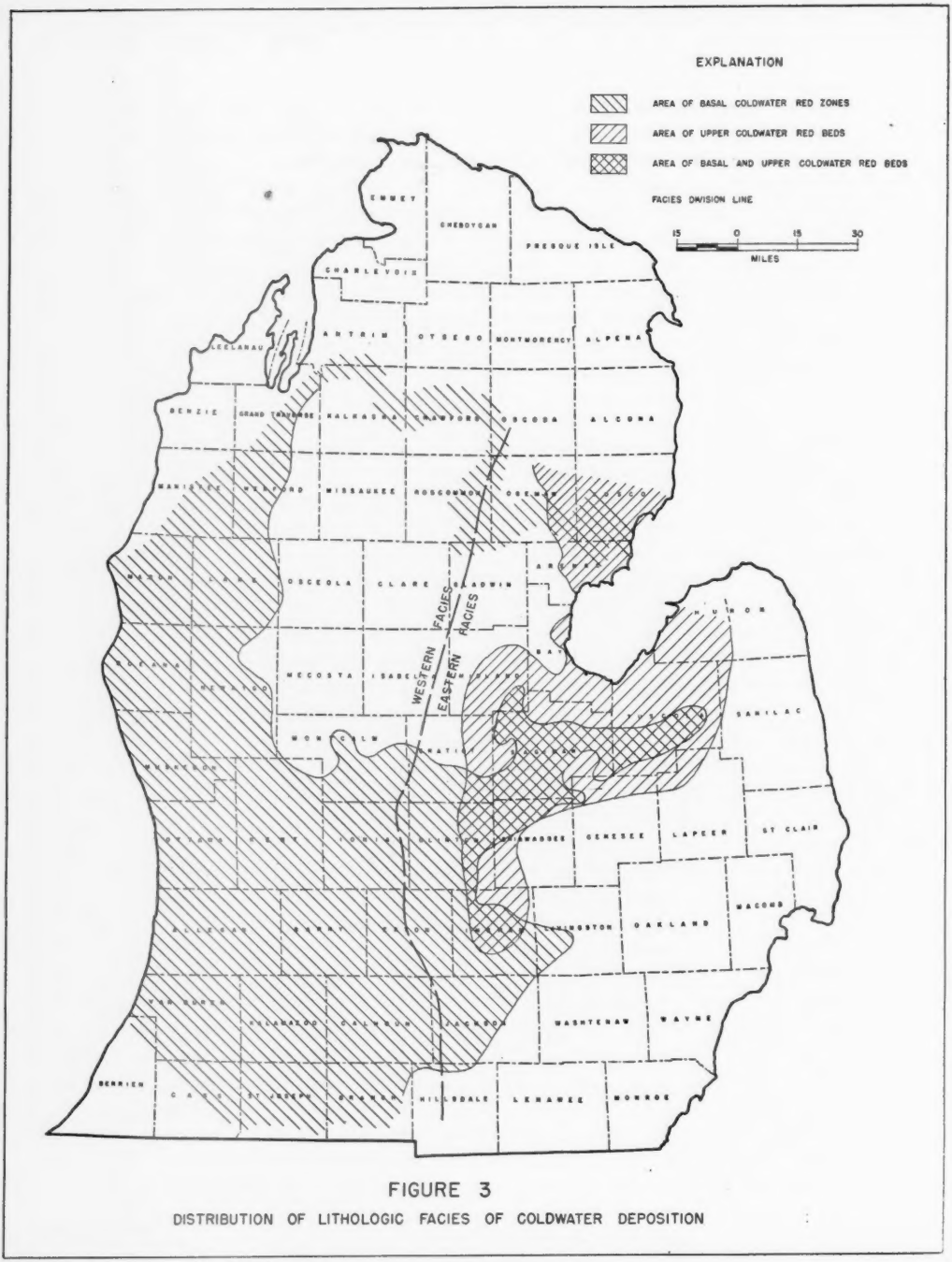


FIGURE 3

DISTRIBUTION OF LITHOLOGIC FACIES OF COLDWATER DEPOSITION

FIG. 3.—Distribution of lithologic facies of Coldwater deposition.

Coldwater ranges from 565 to 1,100 feet in the state, it apparently is not less than 1,000 feet and nowhere greater than 1,060 feet along this facies demarcation.

A common feature of the western facies of the Coldwater formation is the prominent thinning of the sediments from the center to the western margin of the state. A thickness of nearly 1,100 feet is revealed by several wells in Ts. 5–6 N., in Clinton County. From this area westward into Oceana County the Coldwater decreases in thickness more than 500 feet. The thinnest section obtained from well-sample examinations is 565 feet in T. 13 N., R. 16 W., Oceana County. Although these thicknesses are the two extremes, where the top and base of the formation are easily identified, similar thinning of the Coldwater occurs west of the area between Crawford and Calhoun counties. The 1,080 feet of Coldwater measured in eastern Roscommon County thins to 700 feet in Wexford County, 40 miles west.

A slight amount of southward thinning of the Coldwater formation toward the outcrop area is indicated. Thinning in this direction is much less than toward the west. The thickness of the Coldwater in Jackson County is 100–150 feet less than it is in Clinton County 50 miles north. An isopach line representing a thickness of 1,000 feet would extend east and west through the central part of Calhoun County and the northern part of Jackson County. It would maintain a dominantly north-south extent elsewhere in the state.

Thinning is not perceptible from the center of the state toward the area in which Coldwater shale underlies the glacial drift on the north side of the state. The most northern well from which samples are available is in the eastern margin of Kalkaska County (well 1, Fig. 4). A total of 925 feet of Coldwater was penetrated in this well. Wells drilled 30–60 miles south have approximately the same thickness of Coldwater.

EASTERN FACIES

The eastern facies of the Coldwater formation presents a more complex stratigraphic problem that does the western facies. Although the lower limit of the formation is easily identified in well cuttings, the top is poorly defined due to the similarity of the sandy and silty sediments in the upper part of the Coldwater formation to beds in the lower part of the Marshall formation.

In the central part of the Michigan basin the basal Marshall strata are either extremely fine-grained red shaly sandstone or soft red silt ranging in thickness from 40 to 100 feet and occurring 100–130 feet below the top of the Marshall formation. East of central Michigan, within the limits of the eastern Coldwater facies, lithologically identical beds are intercalated with gray shales as far as 500 feet below the top of the Marshall formation. This occurrence led several writers (Cooper, 1906, p. 155; Carlson, 1927, p. 962: Newcombe, 1933, p. 57; Pringle, 1937, p. 22) to conclude that the deposits are lower Marshall in age and correlative with the 560 feet of Marshall sediments reported by Lane (1900, p. 22) in Huron County. This correlation implies a thickening of the

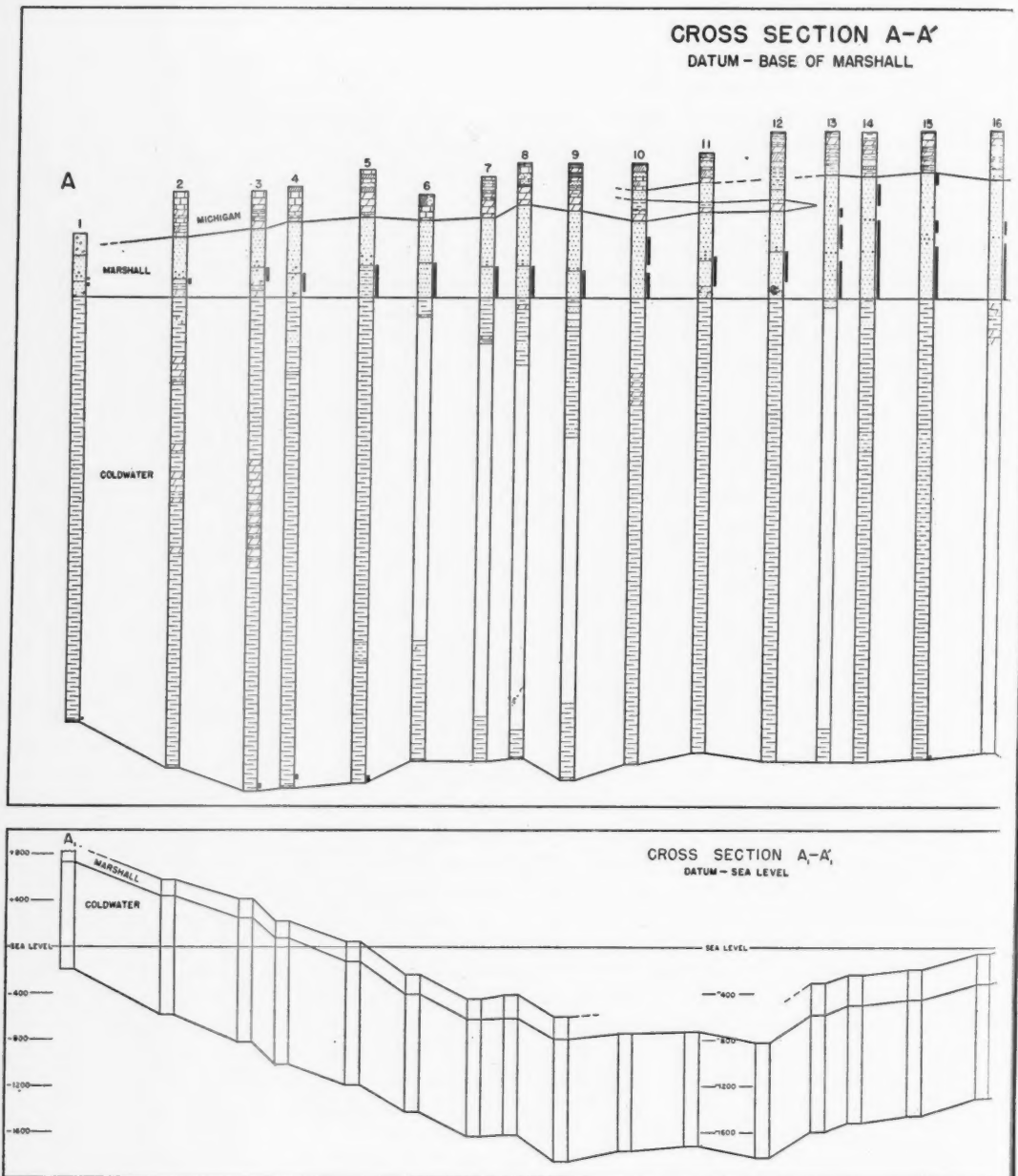
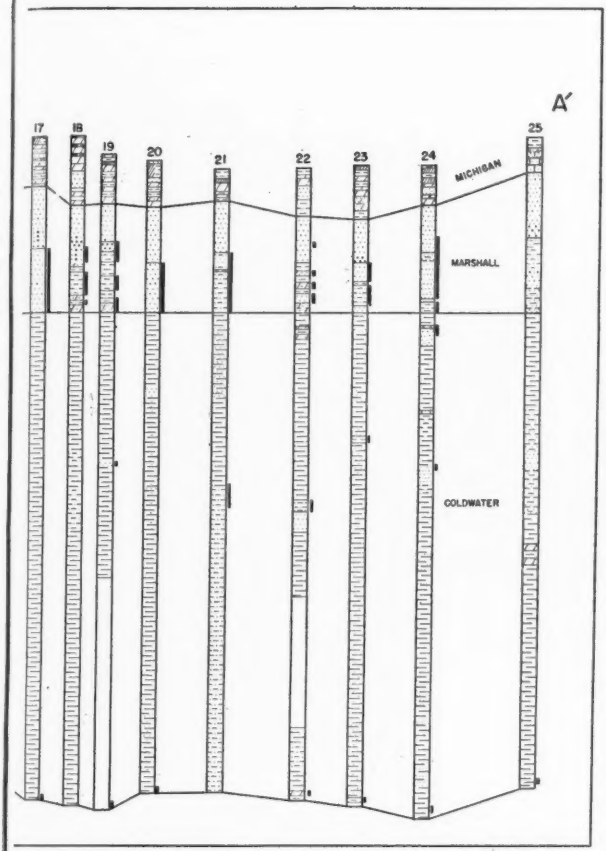
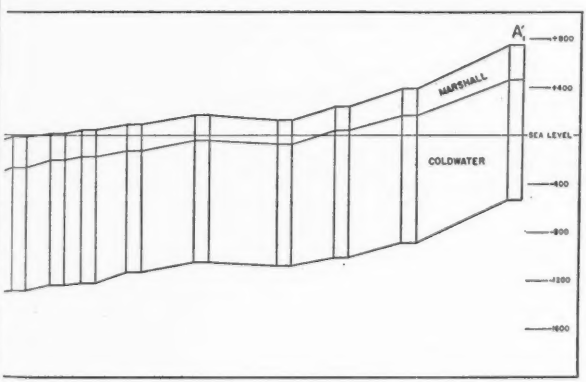


FIGURE 4

FIG. 4.—Cross section *AA'*.





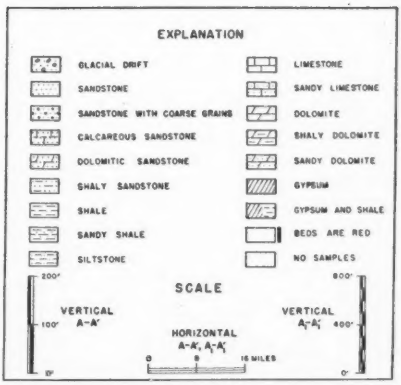


TABLE OF WELLS

NO.	SEC.	TWP.	RNG.	COUNTY	COMPANY	FARM
1	16	26N	5W	KALKASKA	GRAYLING DEV. CO.	STATE 1
2	33	25N	3W	CRAWFORD	DOME OIL DEV. CO.	LUNDGREN 1
3	E	23N	2W	ROSCOMMON	SUN OIL CO.	SALLING HANSON CO., TR 1
4	26	23N	2W	ROSCOMMON	FRANKLIN PET. DEV. CO.	ST. HELEN 1
5	9	21N	1W	ROSCOMMON	GRALE OIL CO.	HALESTRO RESERVE INC. 1
6	33	20N	1W	GLADWIN	E. W. COLLINS	SUTER 1
7	32	19N	2W	GLADWIN	SMITH PET. CO.	SMITH & ROW 1
8	10	18N	2W	GLADWIN	SUN OIL CO.	CAMERON, JR. 1
9	11	17N	2W	GLADWIN	M. F. WHITEHILL	SPICER 1
10	11	16N	3W	ISABELLA	SOCONY VACUUM OIL CO.	CAMPBELL 1
11	28	15N	3W	ISABELLA	MCLANAHAN OIL CO.	DEWSKI 1
12	16	13N	3W	ISABELLA	H. E. BELL	NILSON 1
13	20	12N	3W	GRATIOT	K. B. MONTIGEL, TR.	RAYCRAFT 1
14	9	11N	3W	GRATIOT	RED-MAN OIL CO.	DUCKWORTH 1
15	13	10N	3W	GRATIOT	CARTER COAL CO.	HIRSHMAN 1
16	26	9N	2W	GRATIOT	GULF REFINING CO.	LYON 1
17	12	8N	2W	CLINTON	GRALE OIL CO.	SONNEVILLE 1
18	36	8N	2W	CLINTON	C. W. TEATER	HOLBROOK 1
19	9	7N	1W	CLINTON	C. W. TEATER	WALKER 1
20	29	7N	1W	CLINTON	STORM OIL	PARKER 1
21	1	5N	1E	SHIAWASSEE	DANIELS	CRAWFORD 1
22	23	4N	1W	INGHAM	KALAMAN DRILLERS INC.	SCHUBEL 1
23	14	3N	1E	INGHAM	COLVIN, JR.	GLABER 1
24	23	2N	1W	INGHAM	DARKE BROTHERS	BOYSTON 1
25	1	2S	1W	JACKSON	FISHER ET AL	CLARKE 1

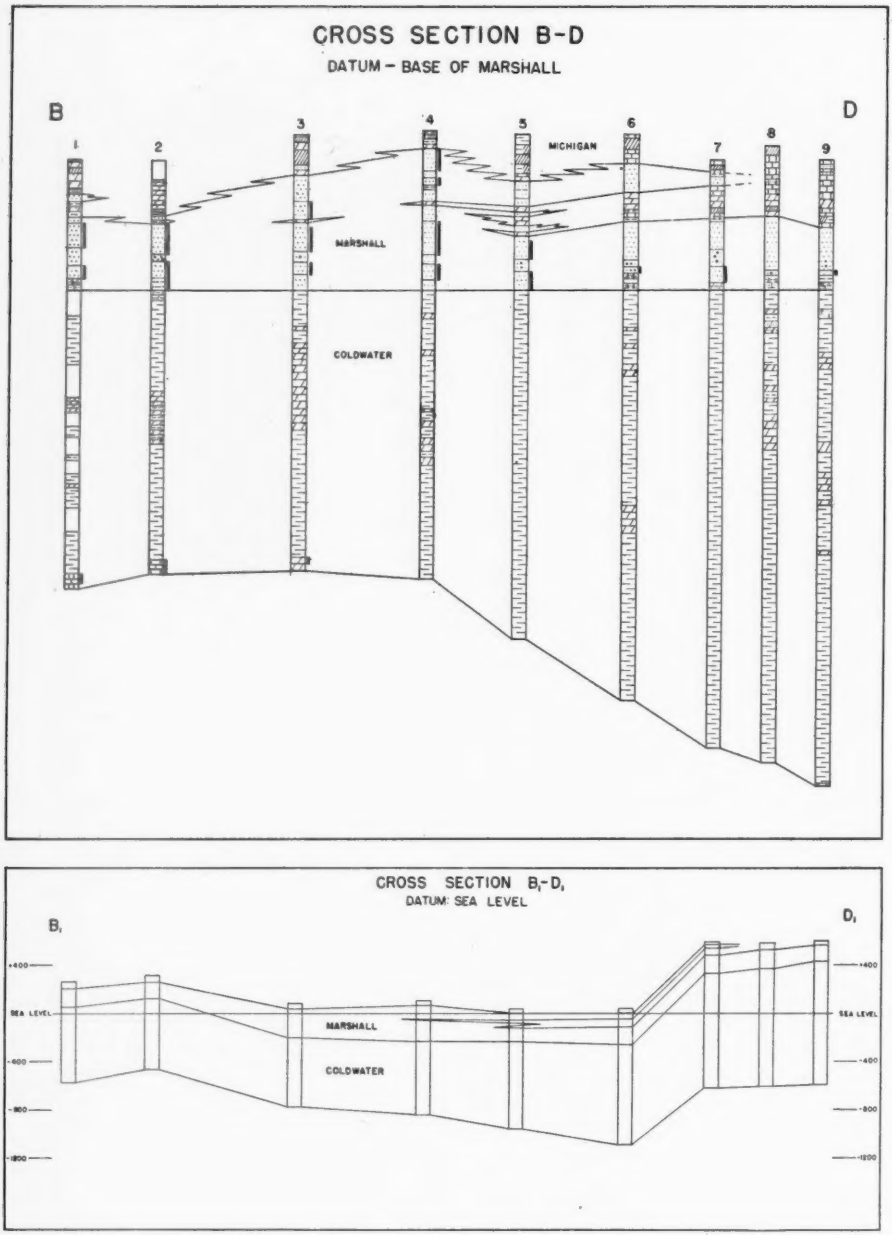
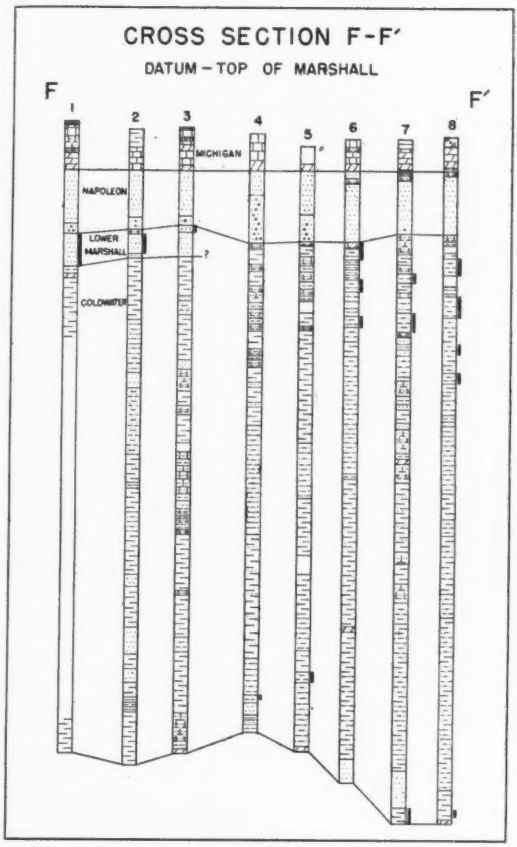


FIG. 5.—Cross sec tion



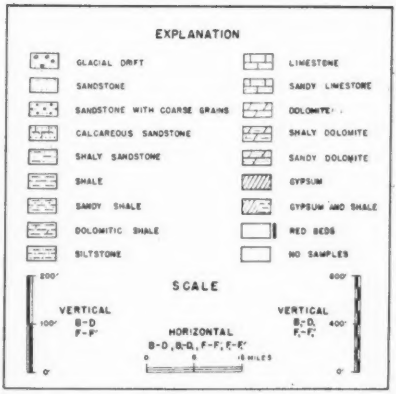


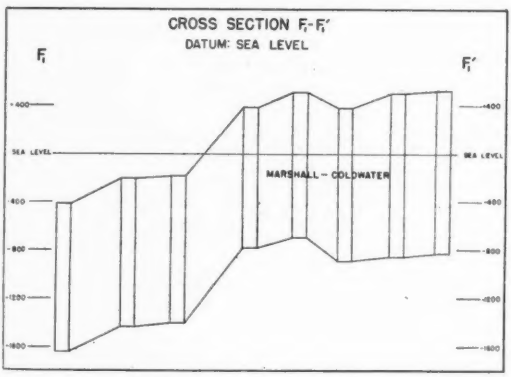
TABLE OF WELLS

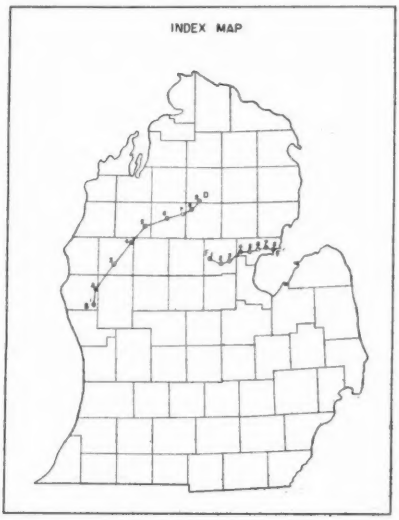
Section B-D

No.	Sec.	Twp.	Rng.	County	Company	Farm
1	36	12S	15W	Oceana	Reed Oil	W. E. Lewis #1
2	24	12S	16W	Oceana	Johnson Oil Refining	Slipp #2
3	26	10S	13W	Lake	R. B. Tamblyn	Cashion et al #1
4	11	20N	11W	Lake	F. J. Ertz, et al	W. Kellogg #1
5	20	24N	8W	Wexford	Marble-Cowe Oil	Smith #1
6	26	23N	7W	Missaukee	Rosar Oil	R. Rohatschalm #1
7	11	23N	6W	Missaukee	Sun Oil	State-Enterprise #1
8	26	24N	4W	Roscommon	V. E. D. Kirtham	William Reer #1
9	33	26N	3W	Crawford	Dome Oil	E. Lundgren #1

Section F-F'

No.	Sec.	Twp.	Rng.	County	Company	Farm
1	10	18N	9W	Gladwin	Sun Oil	A. Cameron, Jr. #1
2	20	18N	1W	Gladwin	Gell, et al	R. Card #1
3	16	18N	2E	Gladwin	W. E. Ross, Tr.	C. W. Kinyon #1
4	21	19N	3E	Arenac	D. Maymurn	John Fox #1
5	15	19N	4E	Arenac	Central Drilling	Fisk #1
6	9	17N	5E	Arenac	R. D. McHugh	Clyde Stevens #1
7	8	17N	6E	Arenac	C. W. Tuster	R. A. Withey #1
8	15	18N	7E	Arenac	Ward Oil	Daley Petty #1





tions *BD* and *FF'*.

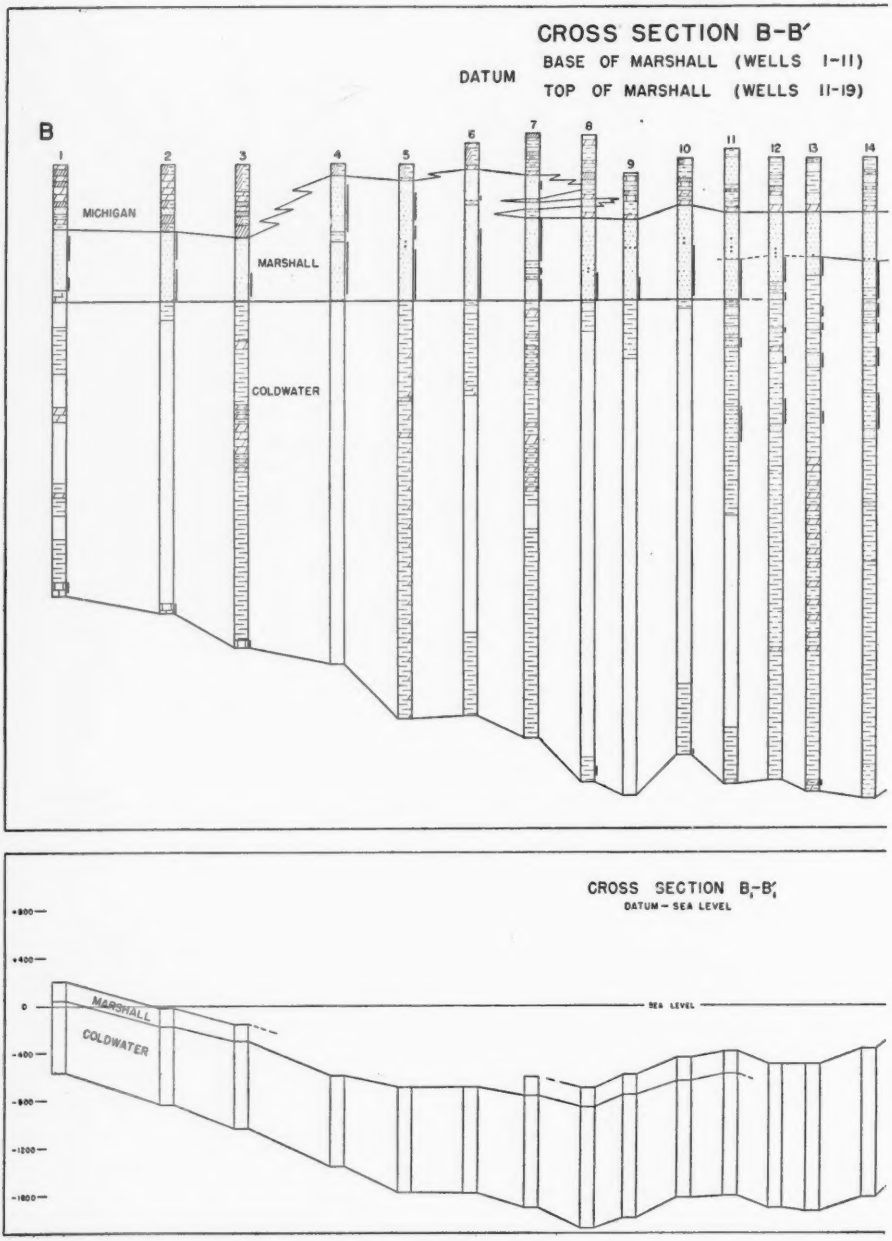
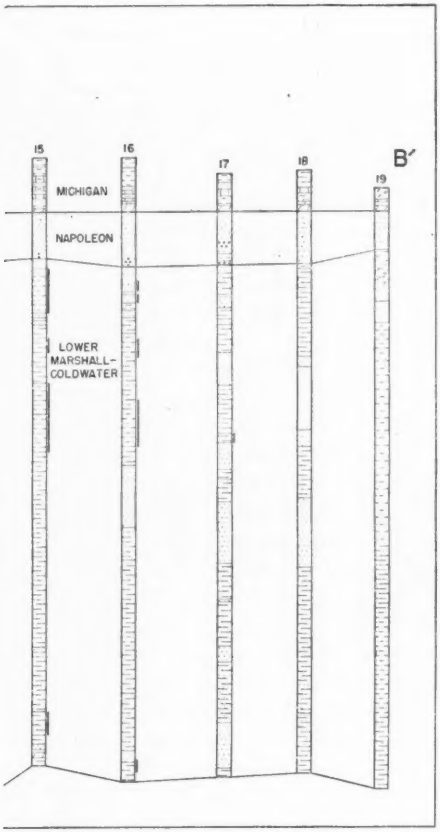


FIG. 6.—Cross section *BB'*.



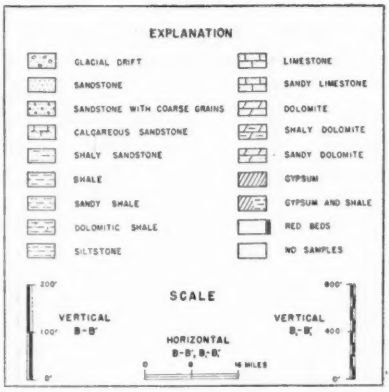
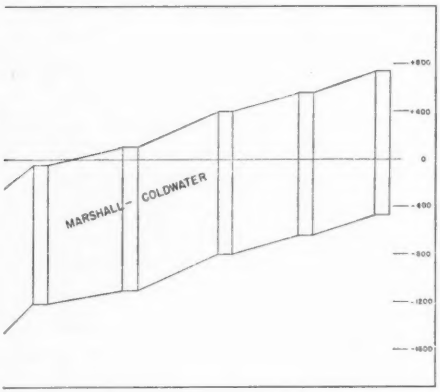
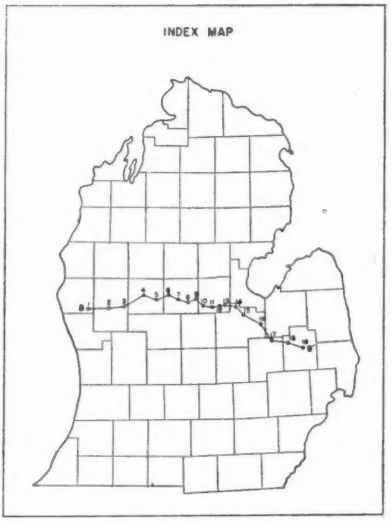
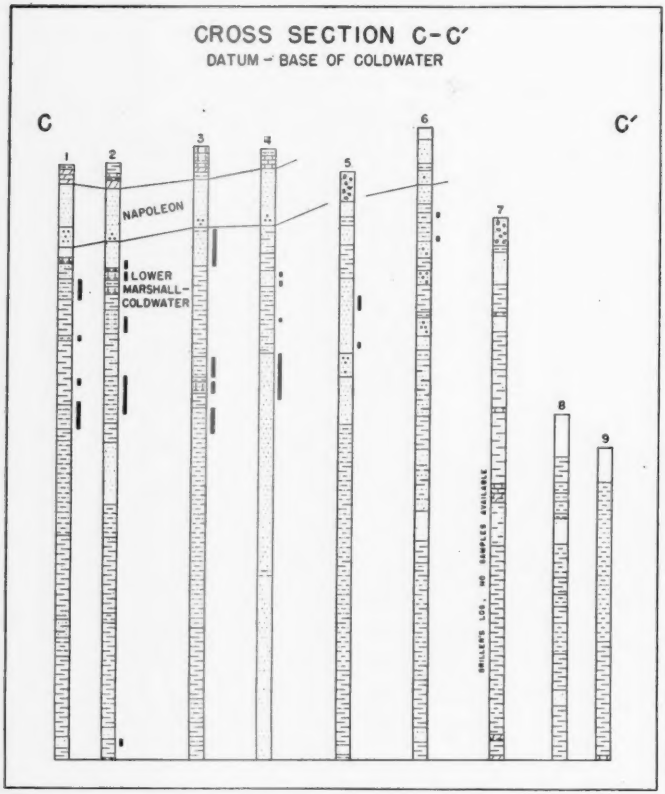


TABLE OF WELLS

No.	Sec.	Twp.	Rng.	County	Company	Farm
1	16	13N	13W	Oceana	Reed Oil	W. H. Lewis #1
2	12	13N	12W	Newaygo	Newaygo Gas & Oil	Bates #1
3	3	13N	11W	Newaygo	Turner Petroleum	Swenson #1
4	35	15N	9W	Mecosta	Taggart Bros., Inc.	Tom Listenwith #32
5	17	14N	7W	Mecosta	Doll, Graves et al	H. Rath #1
6	24	15N	6W	Isabella	Pure Oil	J. W. Embrey #1
7	14	14N	5W	Isabella	C. W. Teeter	Stella Orer et al #1
8	25	14N	4W	Isabella	J. O. Rabel	J. M. Kennedy #1
9	14	14N	3W	Isabella	J. B. McCandless	Bafford #1
10	3	13N	2W	Midland	Pure Oil	Sand-Rock #20
11	10	13N	1W	Midland	Pure Oil	John Mitchell #1
12	11	13N	1E	Midland	McClanahan Oil	John Brooks #1
13	9	13N	2E	Midland	Weller & Esper Oil	Koppenstall #1
14	15	13N	3E	Saginaw	A. H. Weber, Tr.	Kirchner #1
15	10	12N	4E	Saginaw	Carr & Jacobs, Tre.	H. Leandre #1
16	10	11N	6E	Saginaw	Doll, Graves et al	J. F. Brenner #1
17	11	9N	7E	Genesee	A. L. Williams	O. Yetten #1
18	27	9N	9E	Lapeer	Smith Petroleum	Dep. Ldg. Corp. #1
19	17	6N	11E	Lapeer	Rinnenstein Land	James Watson #1







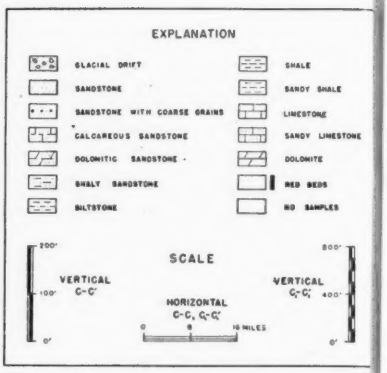


TABLE OF WELLS

Section C-C'

No.	Sec.	Twp.	Rng.	County	Company	Farm
1	30	11N	5E	Saginaw	Bridgeport Oil & Dev't.	Wm. Tobias #1
2	10	11N	6E	Saginaw	Gell, Graves & Moehling	J. P. Hosmer #1
3	8	12N	8E	Tuscola	W. F. Wiechers	O. H. Gray #1
4	8	13N	9E	Tuscola	Gulf Refining	W. Lassiter #1
5	16	13N	11E	Tuscola	Shell Oil	F. Weidan #1
6	32	15N	12E	Huron	Pacific Exploration	Gallagh #1
7	27	16N	13E	Huron	C. W. Teater	Wm. Kerr #1
8	28	17N	14E	Huron	Gordon Oil	Palmer #1
9	1	17N	14E	Huron	L. D. Hendershott	O. Klemp #1

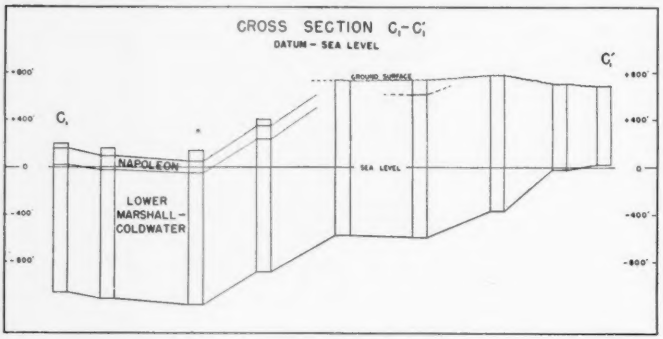


FIGURE 7

FIG. 7.—Cross section *CC'*.

Marshall amounting to more than 100 per cent from the west side of Michigan to the central and eastern part of the state. Data from more recent drilling have caused many of the petroleum geologists in Michigan to correlate the lower redbeds with the Coldwater formation. A thorough investigation of the Coldwater stratigraphy in eastern Michigan is therefore necessary to determine the Coldwater-Marshall relationship and to account for the 560 feet of Marshall beds assumed to be present in Huron County.

The general extent of the eastern and western facies of the Coldwater is outlined in Figure 3. East of the facies division line, wells penetrating the Coldwater formation show varying amounts of extremely fine-grained sandstone and siltstone interbedded with the Coldwater shale. The nature of the Coldwater and Marshall sediments in the eastern part of the state is shown on three cross sections. The most northern one, cross section *FF'* (Fig. 5), extends from the western side of Gladwin County to a well drilled within 2 miles of the northwest shore of Saginaw Bay in Arenac County. A general increase in the quantity of siltstone and sandstone from west to east is one of the most striking features of the section. The eastern half of section *BB'* (Fig. 6) extending from Midland to Lapeer County again illustrates an increasing amount of these clastics toward the east. Although the easternmost wells in the two sections are more than 65 miles apart, the lower Marshall-Coldwater sediments in each well are less than 20 per cent shale. A third cross section *CC'* (Fig. 7) extending from the central part of Saginaw County northeastward into Huron County does not show the eastward sandstone development as well as the other two sections. All of the wells illustrated in this section contain a large amount of siltstone and sandstone in the Coldwater-lower Marshall sequence.

A fair representation of the Coldwater and Marshall beds in the eastern half of the state is given by these three cross sections. Examination of the sections reveals the limitations of general statements which are applicable over the entire area regarding the stratigraphy. The stratigraphic position of the silty and sandy beds is not constant. They may occur in the basal 100 feet of the Coldwater formation (Shiawassee, Genesee, Bay, and Arenac counties) or at any stratigraphic level in the succeeding 1,000 or more feet of Coldwater-lower Marshall sediments. In Gratiot County they appear to be restricted to the middle part of the formation, but in Saginaw County, the adjacent county on the east, they occur at various stratigraphic levels throughout the section. Correlation of individual beds is difficult and in many places impossible with the data available.

Although red colors are uncommon in the siltstones adjacent to the dolomitic facies of the Coldwater, they occur from 6 to 15 miles east of the Coldwater facies division line (Fig. 3). The areal distribution of the redbeds is indicated in Figure 3. A question may arise concerning the western extent of these redbeds in Figure 3, as the lower Marshall of central and western Michigan is commonly characterized by red sediments. Examination of the north-south cross section

AA' (Fig. 4) clarifies this point. Wells 19–24 in the section show the initial occurrence from west to east of the red siltstones and sandstones several hundred feet below the top of the Marshall. The red zones illustrated in the section average 20 feet in thickness and are 600–750 feet above the base of the Coldwater gray shale, which is more than 1,000 feet thick in this area. Wells drilled a few miles west of this section penetrate an almost identical thickness of Coldwater, but no redbeds occur below the uppermost gray shale of the Coldwater, which lies directly under the Marshall formation. It is apparent from their stratigraphic position that these red zones are well within the limits of the Coldwater. They are overlain by 250–300 feet of typical Coldwater shale with a few interbedded siltstones and sandstones characteristic of the eastern facies. It is the westward extent of these lower red zones that is shown in Figure 3. In the area east of section *AA'* (Fig. 4) redbeds become more common in the upper part of the Coldwater formation, and it is very difficult to separate the redbeds of the Coldwater from those of the Marshall.

The redbeds in the lower Marshall and upper Coldwater strata in central and east-central Michigan are predominantly red siltstones. Very fine-grained red sandstones are common, however, and red shale is penetrated in some wells. The occurrence of red sediments from Midland County to Lapeer County is illustrated in the eastern part of cross section *BB'* (Fig. 6). The section reveals 3–5 red zones at different stratigraphic levels from 90 to 500 feet below the top of the Marshall sandstone. The highest and lowest of these zones are the most persistent. The uppermost red zone, consisting of 40–100 feet of red sandstone and siltstone at the base of the Napoleon sandstone, is equivalent, in part at least, to the lower Marshall beds. The lowermost red zone consists of 50–75 feet of red siltstone and shale occurring 400–500 feet below the top of the Marshall. This zone extends farther eastward than any other red zone in the Marshall or Coldwater formations. Between the upper and lower red zone, one to three beds of red siltstone and sandstone, as well as a few gray beds of the same lithologic character, are interbedded with gray shale.

It is apparent from an examination of cross section *BB'* that the Coldwater-Marshall contact is very indefinite east of central Midland County. It has been shown that the lower red siltstones grade laterally into Coldwater gray shales in the central part of the state. A separation of the higher red zones into those of Coldwater age and those of lower Marshall age would not be justified. There appears to be no lithologic feature that can be traced for any appreciable distance which could be used as the basis for the separation. The red zone directly underlying the tan Napoleon sandstone in this area must be partly equivalent to the red lower Marshall strata which are clearly defined in western Midland and Isabella counties. The fallacy in using the base of this uppermost red zone as a criterion for the Coldwater-Marshall division in eastern Michigan is illustrated by wells 14, 15, 16, and 17 in cross section *BB'* (Fig. 6). It is apparent that the 115 feet of dark red siltstone in well 15 grades laterally into red and tan sandstones

and gray shales. Similar conditions are illustrated in the other cross sections that extend into the area of Coldwater-Lower Marshall redbed occurrence (section *FF'*, Fig. 5; section *CC'*, Fig. 7).

Toward the margin of the area in which the Coldwater-lower Marshall redbeds occur the number and thickness of the red zones diminish. The occurrence of the redbeds near the western margin has already been discussed. Very little information is available concerning the northern extent of the red sediments other than the restriction of the lower red zones to the area east of the anticlinal fold in Arenac and Ogemaw counties (cross section *F'*, Fig. 5). There are no redbeds in the Coldwater-Marshall strata on the crest of thi anticlinal area, although red colors occur at the west in the lower Marshall sediments in the region where the Marshall and the Coldwater formations can be separated.

There is a gradual disappearance of the red zones toward the eastern and southern margins of the area in which they occur. Cross section *BB'* (Fig. 6) illustrates the decrease and disappearance of red color from the sediments. The only red zone recognized in Genesee and Lapeer counties is the lowest one, which is approximately 25 feet thick and occurs 400–500 feet below the top of the Marshall. This zone is absent east of the extreme northwest part of Lapeer County and no red sediments are found in the entire Coldwater-Marshall sequence of rocks.

The disappearance of the red color from the Coldwater-lower Marshall strata does not simplify the separation of the two formations in the eastern part of the state. The interval between the Napoleon sandstone and the Sunbury black shale is composed of 1,100–1,300 feet of interbedded sandstone, siltstone, and shale. There is no lithologic unit which may be used as a basis for separating the two formations in their subsurface occurrence. The individual beds of both coarser and finer clastics are not continuous and appear to grade laterally into one another. Attempts to establish a subsurface stratigraphic division between the Coldwater and Marshall formations from the data now available may lead to misinterpretations of the stratigraphy in this area.

The thickness of the Coldwater in the eastern part of the Lower Peninsula is not measurable due to the indefinite nature of the top of the formation. However, the examination of the interval from the top of the Marshall to the base of the Coldwater is of interest. With the exception of eastern Arenac, eastern Ogemaw, Iosco, and Huron counties, this interval varies less than 90 feet in all counties embracing the eastern Coldwater facies north and east of Clinton County. In the extreme northwest township of Saginaw County there is a total Coldwater-Marshall thickness ranging from 1,200 to 1,220 feet. In Lapeer County, 60 miles southeast, 1,190–1,220 feet are recorded. The interval amounts to 1,240 feet in the southeast corner of Roscommon County, 60 miles north of Saginaw County. The minimum thickness observed within the area indicated was 1,160 feet in the western part of Saginaw County.

The Coldwater-Marshall thickness increases markedly not far east of north-

central Arenac County and western Ogemaw County (section *FF'*, Fig. 5). Wells drilled in the north-central part of Arenac County penetrate 1,200–1,240 feet of Coldwater-Marshall sediments. Twelve miles east, 1,350 feet are drilled. Less than 10 miles farther east, beyond the extent of section *FF'*, this interval approaches 1,500 feet. These sediments vary from 1,320 to 1,470 feet in thickness in Iosoc County northeast of Arenac County. It is shown in the discussion of the Marshall formation that the Napoleon sandstone is nowhere greater than 160 feet and nowhere less than 90 feet in thickness in this area. The eastward thickening is therefore a feature of the Coldwater-lower Marshall sediments.

CHARACTER OF DEPOSITIONAL BASIN

Several conclusions regarding the nature of the basin in which the Coldwater sediments were deposited may be made from the data now available. The westward thinning of the sediments and the gradual lithologic change from dolomites and shales in the west to shale, siltstone, and sandstone in the east are strong evidence of an eastern source of sediments. The rather abrupt thickening of the Coldwater-lower Marshall deposits from Arenac and western Ogemaw counties into Iosco County may indicate a localization of the main source of sediments northeast of this area.

Some information pertaining to the size of the area of deposition is afforded by the small amount of thinning on the south, the absence of thining on the north, and the lithologic character of the western sediments. The absence of north-south thinning implies an original extent of the Coldwater sediments far beyond the present boundary of the formation. The absence of clastics other than fine-textured shale, and the increasing development of chemically precipitated sediments in the western margin of the state suggest that these sediments were deposited an appreciable distance from the former western limit of the Coldwater deposits.

Examination of the several cross sections included in this report reveals a thinning of the Coldwater strata over anticlinal folds in the Michigan basin. This relationship was suggested by Newcombe (1933, p. 81). A thinning of the combined Coldwater-lower Marshall beds over the anticline in Arenac County is shown in section *FF'* (Fig. 5). The absence of the top of the Coldwater on the Howell anticline in the southeastern part of the state makes it difficult to determine the amount of thinning of the formation over the structure. There is, however, a thinning toward the anticline from the north, west, and east. Thinning over the smaller and more poorly defined anticlines in the central and western parts of the Michigan basin is indicated, but is of such small magnitude that it may be questioned. This thinning of the Coldwater over the larger anticlines and possibly over the smaller ones indicates that these folded structures antedate Coldwater sedimentation. Ballard (1938, p. 1,548) reports a personal communication from C. C. Addison in which the latter suggests a thinning of the basal Mississippian beds over oil-producing structures in Allegan County.

The marine sedimentation basin in which the Coldwater sediments were deposited appears to have occupied a large area comparable with the size of the basins in which older Paleozoic sediments in Michigan were deposited. The basin contained topographic irregularities of varying sizes due to the expression of folding in the older rocks on the sea floor. Sediments entering the basin from the east consisted of sands, silts, and muds. Variations in the volume of these sediments and in the current and wave action within the eastern part of the depositional basin caused an interfingering of these clastics as they were deposited. Toward the close of Coldwater time some of the streams entering the basin apparently flowed from an area in which red ferruginous sediments had originated. These red sediments were carried into the basin and were deposited in an interfingering sequence similar to that of the other Coldwater deposits.

Fine muds were settling out of the more open sea on the west beyond the area where the coarser clastics were being deposited. The precipitation of carbonate deposits occurred at intermittent times in the quieter and deeper waters. They became more common still farther west where less mud was transported by the water. The influence of a western landmass on the present Coldwater deposits appears to have been negligible.

MARSHALL FORMATION

OUTCROPS

General area.—The Marshall formation is covered with glacial drift in most of the outcrop area and only few natural exposures of the sandstones are found. All of the larger exposures in the southern part of the state are in old quarries, most of which were abandoned long ago. Surface appearances of the Marshall occur in Hillsdale, Jackson, and Calhoun counties in southern Michigan, Ottawa County in southwest Michigan, and in eastern Tuscola, western Sanilac, and northern Huron counties comprising the "Thumb" area of eastern Michigan. The outcrops in Huron County are discussed separately from the other Marshall outcrops because they present a separate problem.

Hillsdale County.—The most southern exposure of Marshall strata in the state where more than 10 feet of section is exposed is about 1 mile northeast of Osseo, in the northwest corner of Sec. 4, T. 7 S., R. 2 W., in Hillsdale County. The outcrop consists of 20 feet of thin-bedded, very fine-grained argillaceous sandstone. The sandstone is buff to greenish buff in color in the upper part of the exposure and rust brown in the lower part. Numerous fossils are in the talus.

North and west of Osseo, old quarries at Hillsdale and Jonesville provide outcrops of Marshall strata. The quarry at Hillsdale is within the city limits, in the SW. $\frac{1}{4}$ of Sec. 22, T. 6 S., R. 3 W. Although more than 25 feet of strata was exposed in this quarry many years ago, it has been filled in to such an extent that now less than 8 feet of bedrock is available for examination. The rock is an olive-green to buff, thin-bedded, very fine-grained sandstone.

The quarry at Jonesville is at the southern edge of the city limits on the east bank of an old mill race about 200 feet north of the mill pond. Thirty feet of tan to greenish gray, thin-bedded, very fine-grained sandstone is exposed. Fossils are present in the talus although they are not abundant.

A petrographic study was made of a sample of the sandstone exposed at Jonesville. More than 90 per cent of the sandstone is quartz. Other constituents, in order of their abundance, include chert, muscovite, biotite, and plagioclase

FIG. 8.—Abandoned quarry in Marshall sandstone at Stony Point, Jackson County, Michigan. Photograph by G. M. Ehlers.

feldspar. The sandstone contains minor amounts of chlorite, ilmenite, rutile, and zircon.

Several small and isolated exposures of Marshall strata are in the northern tier of townships in Hillsdale County. The most accessible are in a road cut 3 miles east of Litchfield in the SW. $\frac{1}{4}$ of Sec. 18, T. 5 S., R. 3 W., and in road cuts around Mosherville Station in Sec. 2, T. 5 S., R. 3 W. The beds at these localities consist of very fine-grained, olive-green to buff sandstone which is very similar in lithologic character to the strata at Jonesville and Hillsdale. However, 6 feet of sandstone exposed in a new pipe-line ditch $1\frac{1}{2}$ miles north of Jerome in the NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 7, T. 5 S., R. 1 W., is lithologically very different. The rock is medium-grained, porous and friable sandstone which is light buff and grayish white in color.

The fine-grained, fossiliferous sandstones of Hillsdale County are generally

FIG. 9.—Quarry in upper Marshall sandstone at Napoleon, Jackson County, Michigan.

considered to belong in the lower Marshall strata. The medium-grained, non-fossiliferous sandstone near Jerome is more similar to the sandstone at Napoleon, 13 miles northeast, than to any of the other sandstones in Hillsdale County.

Jackson County.—The largest exposure of Marshall deposits in the state is in southern Jackson County at the abandoned Stony Point quarry (Fig. 8) southwest of Hanover in Sec. 31, T. 4 S., R. 2 W. The section is as follows.

SECTION OF MARSHALL STRATA EXPOSED AT STONY POINT IN SEC. 31, T. 4 S., R. 2 W.

	Feet	*Inches*
Sandstone, fine-grained, tan, very friable	16	
Sandstone, fine- to medium-grained, buff; contains some small, gray, lenticular "mud lumps"	10	
Sandstone, fine-grained, buff to brown; contains molds of pelecypods and goniatites coated with limonite		6
Sandstone, fine- to medium-grained, buff to brown, friable, micaceous	9	6
Sandstone, fine- to medium-grained, buff, massive; contains a few poorly preserved fossils	13	
	49	

The mineral composition was determined of a sample of the sandstone taken 5 feet above the base of the exposure. About 95 per cent of the rock is quartz, feldspar, and mica. The feldspar content of the sandstone varies from 5 to 10 per cent and is greater than that of the sandstone at Jonesville.

The Stony Point exposure probably belongs in the central part of the Marshall formation. Beds in the upper part of the Marshall crop out at Napoleon northeast

of this locality and sandstones in the lower part of the formation are in Hillsdale County on the south. Lithologically, the sandstone at Stony Point possesses characteristics common to both the coarser sandstones at Napoleon and the finer sandstones on the south.

Another good exposure of Marshall sandstone in Jackson County is in the quarries at the east edge of Napoleon, Michigan (Fig. 9). This is the type locality of the Napoleon sandstone described by Winchell (1861, p. 89). Winchell measured 75 feet of sandstone in the area of the quarries. Twenty-five years later, Rominger (1876, p. 80) recorded 50 feet of sandstone at the same locality. At the present time less than 20 feet of bedrock is exposed. It consists of medium-grained, friable, non-fossiliferous sandstone. The strata are very light buff on fresh surface but weather to medium-gray. The sandstone appears massive from a distance but on closer examination, particularly of the weathered surfaces, a series of thin beds are seen. This thin bedding makes it possible to quarry large flat blocks of sandstone 1–4 inches thick.

There is no noticeable change in the sandstone from the bottom to the top of the quarry. The sand grains are subangular to subrounded and do not have frosted surfaces. Quartz and chert are the chief constituents of the sandstone. Biotite and chlorite are common and minor amounts of tourmaline, ilmenite, and zircon are present. The feldspar content of the sandstone is very small.

Outcrops of Marshall beds elsewhere in Jackson County are rare. The formation is very close to the surface at several localities in the southern part of the country but no bedrock was observed.

Calhoun County.—The Marshall sandstone is very near the surface at many places along the Kalamazoo River Valley between Homer and Battle Creek in Calhoun County. The presence of several quarries along the river make this area the best in the state in which to study the Marshall strata.

Down the river from Homer, an abandoned quarry on the west river bank in the NE. $\frac{1}{4}$ of Sec. 20, T. 3 S., R. 4 W., reveals 22 feet of non-fossiliferous sandstone. The rock is the most coarsely grained Marshall sandstone exposed in southern Michigan. It is a porous, friable rock composed of medium to coarse sand grains and ranges in color from buff to grayish white. The sandstone is more massive than that at Napoleon.

The next outcrop west, near Morengo, is one of the few natural exposures of more than 5 feet of Marshall sandstone in southern Michigan. The outcrop is on the south bank of Kalamazoo River near the center of Sec. 30, T. 2 S., R. 4 W. Approximately 14 feet of small- to medium-grained, light tan to grayish white sandstone rises above the river flat. The lower 5 feet is mostly covered, but the remaining 9 feet is very friable, porous, massive sandstone showing some cross-bedding. A few feet of this sandstone is exposed in a road cut 1 mile southeast in Sec. 32 of the same township.

The quarry at Marshall, Michigan, from which Winchell (1861, p. 84) adopted the name of the Marshall formation, now furnishes much less section to examine

than it did in Winchell's time. Winchell described 25 feet of rock in 1861, whereas now only 9 feet is exposed. Undoubtedly 25 feet of sandstone is present, but most of it is covered. It is only due to recent quarry operations that the 9 feet is exposed The rock is a fine-grained, olive-green to tan sandstone which is rather massive at the base and thin-bedded and platy toward the top. A few large flakes of muscovite are in the sandstone. Although a few pelecypods are present throughout the 9 feet, an abundance of fossils occurs in a bed of shaly, ferruginous sandstone 3 feet above the base of the exposed section. The extremely fossiliferous bed is soft on fresh surfaces and complete fossils can be obtained, but the bed becomes very hard after it has weathered a short time, and the collection of unbroken fossils is more difficult.

The mineral content of a sample of the sandstone taken one foot above the base of the quarry was determined. Quartz and chert are the most common minerals, comprising about 90 per cent of the sample. Biotite, feldspar, and fragments of mica schist are the other chief constituents. Minor amounts of ilmenite, chlorite, apatite, tourmaline, and calcite are likewise present in the sandstone.

Larger exposures of Marshall strata are along the Kalamazoo River between Ceresco and Battle Creek. A quarry on the north side of the river 1 mile west of Ceresco in the southwest corner of Sec. 24, T. 2 S., R. 7 W., provides the following section.

SECTION OF MARSHALL STRATA EXPOSED IN QUARRY IN SEC. 24, T. 2 S., R. 7 W.

	Feet	*Inches*
Sandstone, fine-grained, thin-bedded, argillaceous and hard	8	8
Sandstone, fine-grained, thin-bedded, argillaceous; contains thin bands of limonite molds of ostracods	10	
Sandstone, fine- to medium-grained, thick-bedded, tan; contains some large flakes of mica	5	
	23	8

The entire section is argillaceous as compared with the sandstone at Marshall. The argillaceous content makes it harder and better cemented. When crushed, the sandstone resembles light brown silt. Ostracods were the only fossils observed in the sandstone.

Two miles farther downstream, on the north side of the river in Sec. 15, T. 2 S., R. 7 W., is the abandoned Clark quarry. The north bank of Kalamazoo River between these two quarries seems to be composed largely of Marshall sandstone, but bedrock is seen in few places. The 22 feet of sandstone exposed in the Clark quarry is generally more coarse-grained than that at the Ceresco or Marshall quarries. The lower and more massive 12 feet consists of fine-grained sandstone with a few disseminated grains of medium size, but in the upper 10 feet coarser sand grains are more abundant. The sandstone ranges in color from olive-green to grayish tan.

A petrographic examination of a sample of this sandstone 13 feet above the base of the exposure shows a feldspar content much greater than that of other

Marshall sandstones in Michigan. Orthoclase, microcline, and varieties of plagioclase feldspar constitute at least 20 per cent of the grains in the sandstone. Approximately 75 per cent of the minerals are quartz and chert. Biotite, muscovite, fragments of mica schist, rutile, and zircon are the remaining constituents.

Marshall strata underlie a thin soil covering at several places in Battle Creek and are commonly exposed in excavations in the city. The bed of Kalamazoo River has been reported to be fossiliferous Marshall sandstone in the vicinity of the Kendall Street and the Emmet Street bridges. Although the fossiliferous beds were not seen, the following section was measured on the west bank of the river about 100 feet upstream from the Emmet Street bridge.

SECTION OF MARSHALL STRATA EXPOSED NEAR EMMET STREET BRIDGE, BATTLE CREEK, MICHIGAN

	Feet	*Inches*
Sandstone, fine- to medium-grained, tan to gray, very friable, with some indications of cross-bedding	7	
Clay, gray, soft		6
Sandstone, fine- to medium-grained, greenish gray to tan; beds are 1–6 inches thick	2	
Sandstone, fine-grained, greenish gray	3	6
	13	

Ottawa County.—No exposures of the Marshall were observed between Battle Creek and Holland, Michigan. A quarry in Sec. 22, T. 5 N., R. 15 W., east of Holland and southeast of Waverly, marks the most northern and western surface occurrence of the Marshall formation in this part of the state. The quarry, which is as much as 40 feet deep in some parts, is now nearly filled with water. On the east side of the quarry 2 feet of gray to buff, fine-grained sandstone stands above the water level. The lower 6 inches is very fossiliferous, brown, ferruginous, fine-grained sandstone. The high content of iron oxide makes the rock very hard.

Slabs of sandstone taken from the lower parts of the quarry for building purposes were examined in the town of Holland. The sandstone is greenish tan, fine-grained, silty, and micaceous. A thin section of the rock was made and the mineral content determined. The constituents are essentially the same as in other fine-grained Marshall sandstones in southern Michigan. Feldspars comprise more than 10 per cent of the sample. Flakes of biotite and muscovite and fragments of mica schist also are present.

Tuscola and Sanilac counties.—Several exposures of upper Marshall (Napoleon) sandstone occur in northeastern Tuscola and northwestern Sanilac counties in the vicinity of the North Branch of Cass River. Gordon (1900, p. 12) estimated that about three-fifths of Sanilac County is underlain by Marshall sandstones. Rominger (1876, p. 78) reported outcrops of coarse-grained sandstone in the towns of Elkland and Novesta in Tuscola County and in the towns of Greenleaf and Argyle in Sanilac County. Most of the rock is thinly bedded, but in some places beds up to 3 feet in thickness occur between the thin-bedded deposits. Good exposures in Sanilac County are along the north bank of a small stream in the

northwest corner of Sec. 13, T. 14 N., R. 12 E., and in the northeast corner of Sec. 19, T. 13 N., R. 13 E. A sample of the sandstone from the village of Tyre in Sec. 1, T. 14 N., R. 13 E., Sanilac County, where upper Marshall beds reach the surface was sectioned for petrographic study. Quartz and chert comprise most of the sand grains. There are minor amounts of feldspar, zircon, ilmenite, biotite, muscovite, and apatite.

Some clues regarding the lithologic character of the beds immediately underlying the Napoleon medium- to coarse-grained sandstone were found near Argyle in Sanilac County in the northeast corner of Sec. 28, T. 13 N., R. 13 E. The rocks dredged out and dumped along the banks of a small stream at this locality consist of blue-gray shale and fine-grained, greenish brown sandstone. Among these rocks some fragments of conglomerate were found which are very similar to the "peanut conglomerate" of northern Huron County. Although no bedrock was definitely recognized, parts of the stream bed appeared to be blue-gray shale. Rominger (1876, p. 78) described beds of shale and fine-grained sandstone in bluffs along the side of Cass River in Sec. 7, T. 13 N., R. 12 E., Sanilac County.

SUBDIVISION IN SOUTHERN MICHIGAN

A division of the Marshall formation into two distinct members is very difficult in most parts of the state. The division in the area of outcrops has been based on the presence of fossils in the lower, fine-grained sandstones of lower Marshall and the absence of fossils in the upper, coarser-grained Napoleon sandstone. These criteria are of little aid in the division of the Marshall in subsurface work and are not applicable everywhere in the outcrop area. There are many feet of fine-grained sandstone exposed in Calhoun County in which fossils are exceedingly scarce. A few fossils are found in coarser-grained sandstones at Stony Point in Jackson County, although their occurrence in rocks of this type is not common.

The use of grain size to determine whether an outcrop is in the upper or lower parts of the Marshall is very questionable. Medium-grained sandstones are not entirely restricted to the upper part of the Marshall but may occur in the lower part of the formation interbedded with fine-grained sandstone. Conversely, fine-grained sandstones are not confined to the lower part of the formation, but occur interbedded with the more coarse-grained sandstones in the upper part of the Marshall, especially in the southwestern part of the state.

The variations in grain size are even more evident in the wells that penetrate a complete Marshall section a few miles basinward from the outcrop area. Cross section *GG'* (Fig. 10) illustrates the lithologic character of the Marshall formation in subsurface adjacent to the outcrop area in southern Michigan extending from Jackson County northwest into Ottawa County. The Coldwater-Marshall contact in this area is marked by a distinct change in lithology. The Marshall sediments overlying the Coldwater gray shale consist of fine-grained, tan sandstone and medium-grained, tan to white sandstone. Thin discontinuous lenses of gray

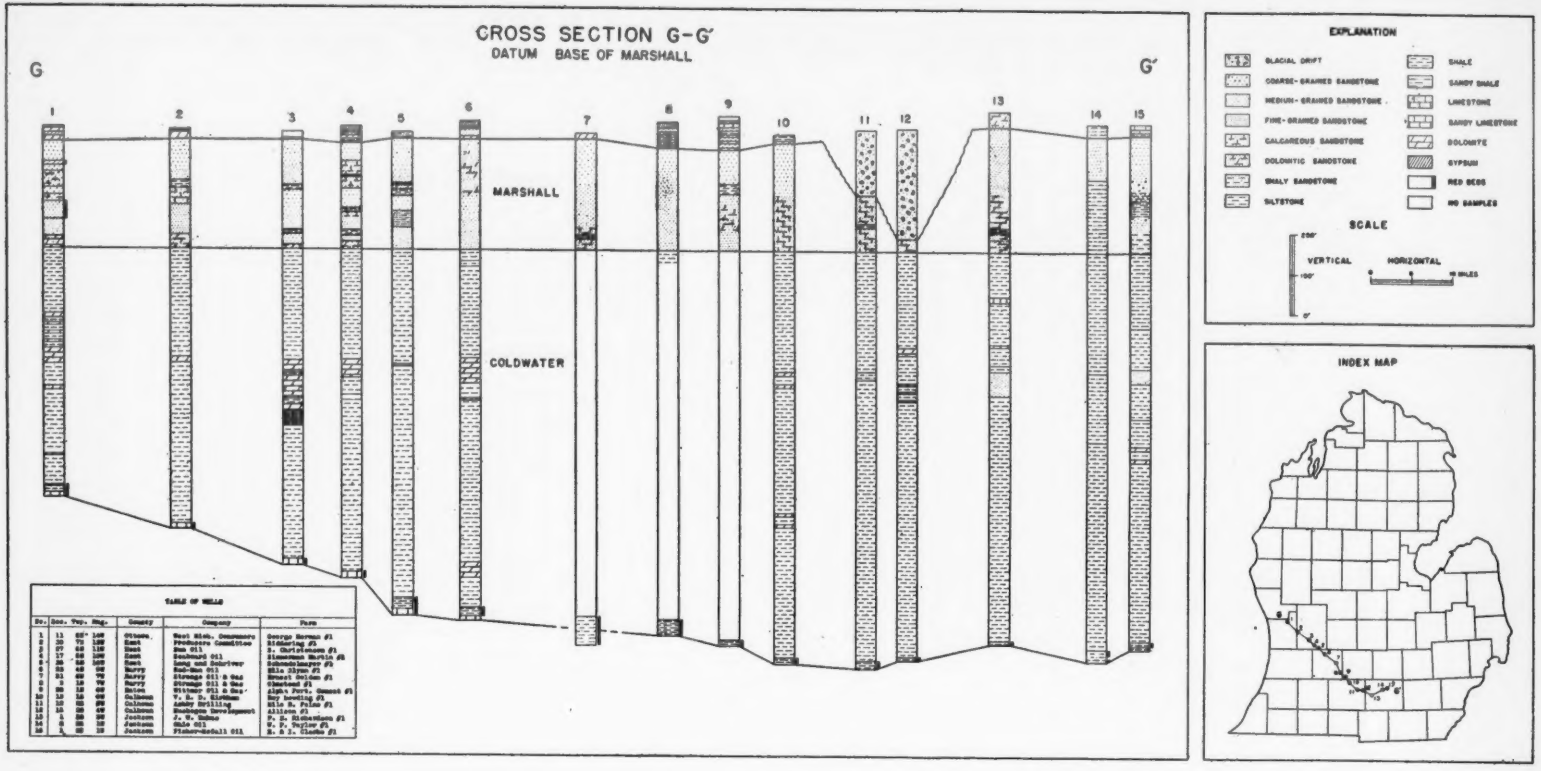


FIG. 10.—Cross section *GG'*.

shale occur at various stratigraphic positions within the Marshall formation in half of the wells illustrated in cross section *GG'*. The lowermost Marshall beds are fine-grained and commonly calcareous or dolomitic.

A well in north-central Calhoun County (well 9, cross section *GG'*, Fig. 10) contains a Marshall sequence very similar to that described by Winchell (1861, p. 139) from his examination of outcrops. The well penetrated 130 feet of medium-grained, white to tan, porous sandstone overlying 135 feet of grained, calcareous sandstone. This is an ideal section for dividing the formation into two members. The upper 130 feet closely coincides with the original description of the Napoleon sandstone and the lower 135 feet represents the lower Marshall sandstone. Unfortunately, however, the section is not typical of the Marshall formation. The wells in Eaton, Barry, Kent, and Ottawa counties shown on cross section *GG'* do not demonstrate a singular marked lithologic change near the center of the formation. Generally, the coarser sandstones are in the upper half of the formation but the western wells shown in section *GG'* (Fig. 10) are exceptions. A well in north-central Barry County (well 5, Fig. 10) penetrated 275 feet of Marshall sandstone of which all but 40 feet in the center of the formation is fine-grained. If a few feet of the upper part of this sandstone should appear in outcrop, it would probably be noted as lower Marshall strata.

It is concluded from a study of the surface and subsurface character of the Marshall formation in southern Michigan that a division of the Marshall into upper and lower members is not advisable when the division must be based on lithology alone. A division of outcrops based on the presence or absence of fossils may be possible in localities where the medium-grained sands are restricted to the upper part of the formation and the fine-grained sands are restricted to the lower part. Even under these conditions the value of a division of the formation is questionable, because the division could not be extended laterally more than a few miles owing to the lack of outcrops and to the lateral changes of lithology.

SUBSURFACE IN WESTERN AND CENTRAL MICHIGAN

Occurrence of red sediments.—The Marshall formation exhibits several marked lithologic changes basinward from the outcrop area. Although red sediments are absent in the outcrops and appear only in the most western well of section *GG'* (Fig. 10), they are common in the Marshall near the center of the Michigan basin, especially in the lower beds of the formation.

The areal distribution of redbeds in the Marshall formation, where the formation is clearly defined, is shown in Figure 11. Their extent is nearly as great as that of the Marshall itself. They are entirely absent in a relatively narrow area adjacent to the drift-covered outcrop in southern and eastern Michigan. The southern boundary of Marshall redbeds conforms in general with the strike of the strata in southern Michigan.

The eastern limit of red sediments in the Marshall formation shown on Figure 12 may be questioned. In Tuscola, Bay, Arenac, and Ogemaw counties there are

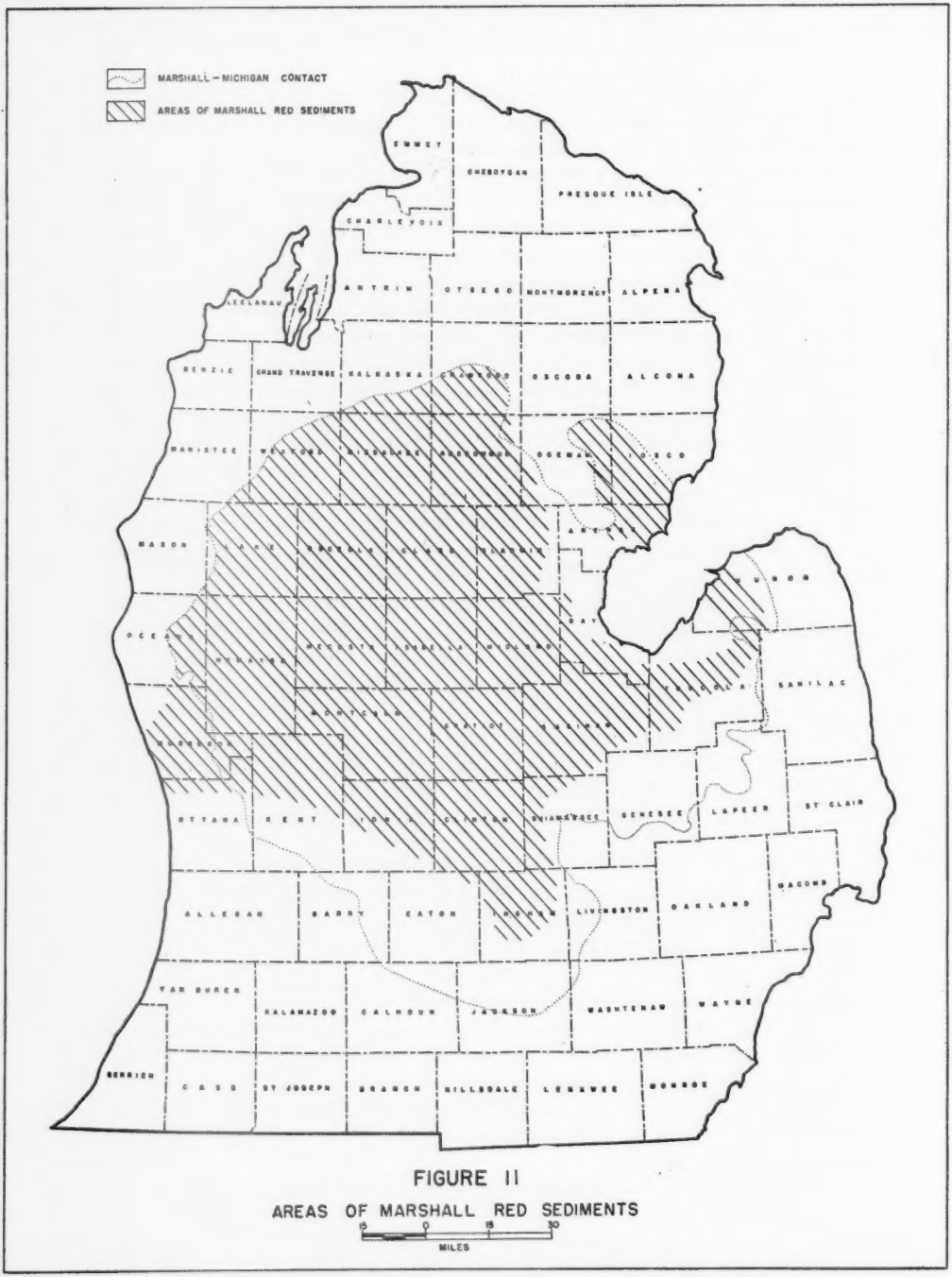


FIGURE 11

AREAS OF MARSHALL RED SEDIMENTS

FIG. 11.—Areas of Marshall red sediments.

redbeds east of the area outlined. In the description of the Coldwater formation the redbeds in these counties are indicated as Coldwater-lower Marshall. East of the area of red Marshall shown in Figure 11, the occurrence of these red zones is limited to strata more than 200 feet below the top of the Marshall. There are no red sediments in the first 100 feet or more of deposits directly underlying the medium- to coarse-grained sandstones in the upper part of the Marshall formation in this area. The eastern limit of Marshall redbeds shown in Figure 11 is therefore the extent of redbeds in the Marshall formation where this formation can be separated from the Coldwater formation in well samples. In those areas where the two formations can not be separated, it indicates the eastern limit of red sediments occurs less than 200 feet below the top of the Marshall formation. Well 17 in cross section *BB'* (Fig. 6) is not included in the area of Marshall red sediments, because the only redbed in this well lies 470 feet below the top of the Marshall.

The relationship of the red color in the Marshall formation to lower Marshall beds and its value as a stratigraphic marker has evoked much discussion. In some small areas the top of the redbeds has been identified as the top of lower Marshall. It was so considered by Eddy (1936, p. 4) in his study of the Crystal oil field in Montcalm County. Kirkham (1932, p. 137) recommended the use of the "Lower Marshall or 'red rock' horizon" as a trustworthy datum for subsurface contour mapping. Prior to the publication of these reports, Newcombe (1929, p. 207) stated that the redbeds were not adaptable for use as a key horizon in the Saginaw oil field.

Enough data are now available to show that a red color in the Marshall deposits is of little value as a stratigraphic marker from a regional point of view, and that the red color is not limited to lower Marshall strata. Cross section *BB'* (Fig. 6) shows the stratigraphic range of red sediments from Oceana County eastward to Genesee County. Although red sediments are more characteristic of the lower beds, they commonly occur in the highest part of the formation in western Michigan. Their thickness and continuity are very irregular (wells 1, 2, 3, and 4, section *BB'*, Fig. 6). The base of the red sediments does not everywhere coincide with the base of the Marshall formation. Any of the included cross sections shows one or more wells in which the color does not extend to the base of the sandstone. As red sediments do not occur in any constant stratigraphic position, it is not practical to attempt a regional separation of the lower Marshall sandstone from the Napoleon (upper Marshall) sandstone on a color basis.

Landes (1944, p. 187) suggested that the division of the Marshall should be based on grain size rather than color in the Porter oil field of Midland County. There is an area in central Michigan from Roscommon County to Clinton County where a division of the Marshall can be made on both color and grain size. This area includes parts of Roscommon, Clare, Gladwin, Isabella, Midland, Gratiot, and Clinton counties. There is a definite lithologic change within the formation, consisting of a noticeable reduction in grain size in the lower part of the section

commonly accompanied by the abrupt occurrence of red color in these finer clastics. Within the area of an oil-producing structure this lithologic change affords an acceptable mapping horizon. The wells in Gladwin County represented on cross section *FF'* (Fig. 5) are in an area in which the Marshall formation can be divided into two well defined members.

Extension of this division toward the west is very difficult. The red color is not limited to the lower part of the Marshall formation and the change in sand grain size does not occur at the same stratigraphic level in many places in western Clare, Isabella, Gratiot, and Clinton counties. The Marshall formation is lithologically similar in the other western counties of the state. In some parts of most of these counties the fine-grained sandstones are restricted to the lower part of the formation and the top of these fine-grained sandstones may be used locally as a stratigraphic marker. However, attempts to determine this marker over the area of even one county are generally unsuccessful. In Newaygo County, in Sec. 35, T. 11 N., R. 13 W., a well penetrated 185 feet of Marshall sandstone of which the top 45 feet is tan sandstone and the remaining 140 feet is red sandstone. The sandstone is fine-grained throughout the section. A well in Oceana County, in Sec. 23, T. 15 N., R. 15 W., penetrated 200 feet of Marshall sandstone. The upper 150 feet is interbedded red and tan, fine- to medium-grained sandstone and the lower 50 feet consists of light gray, fine- to coarse-grained sandstone. These wells show the lithologic variation of the Marshall formation in the western part of the state. It is difficult to establish a typical Marshall section in western Michigan. Cross section *BB'* (Fig. 6) illustrates the variations in color and thickness of the Marshall sediments from west to east.

Relation to Michigan "Stray" sandstone.—Another prominent feature of the Marshall formation northward from the outcrop area in southern Michigan is its irregularity of thickness. Closely associated with the irregularity of thickness is the indefinite nature of the top of the formation. The thickness of the Marshall in the area from Jackson County to Ottawa County represented in cross section *GG'* (Fig. 10) is fairly constant and averages about 275 feet. A thinning of approximately 100 feet occurs 20–30 miles northeast of almost any well shown in this cross section. This change in thickness is illustrated in the southernmost wells of cross section *AA'* (Fig. 4). The Marshall formation in Jackson County is 300 feet thick, whereas 190–230 feet are recorded in Ingham and Shiawassee counties on the north. These figures of thickness represent the interval from the top of the Coldwater formation to the base of the lowest dolomite or shale of the Michigan formation. The sandstone above the lowest dolomite and shale of the Michigan formation in wells 22–25 of cross section *AA'* (Fig. 4) is generally considered to be a "stray" sandstone of the Michigan formation. The stratigraphic relationship of these beds to the sandstones of the Marshall formation is one of the primary stratigraphic problems of the Marshall formation. It is necessary to determine this relationship before generalized statements regarding the thickness and occurrence of the Marshall formation in the western half of Michigan can be made.

Published opinions on the Michigan "Stray"-Marshall sandstone relationship can be classified into two general groups. The first group considers the "stray" sandstones to be reworked and redeposited Marshall sediments. Bergquist (1938, p. 50) points out that this conception of the stratigraphy implies an interruption in sedimentation at the close of Marshall time. Lane and Seaman (1909, p. 81) first suggested an unconformity at the top of the Marshall sandstone. Many years later, Thomas (1931, p. 490) and Kirkham (1932, p. 137) described an unconformity between the Marshall and Michigan formations. Newcombe (1933, p. 81) enlarged upon this concept and suggested that the Michigan "Stray" sandstones were deposited as bars in the Michigan sea following erosion of the top of the Marshall formation. Stearns (1933, p. 101), Eddy (1936, p. 4), and Ball *et al.* (1941, p. 241) have expressed similar opinions.

The second group of views on the Michigan "Stray"-Marshall sandstone suggests a gradational contact between the two formations with sandstones, shales, and dolomites interfingering in an irregular arrangement. Although Cook (1914, p. 64) implied that the contact between the two formations was gradational, he did not discuss the subject. Hard (1938, p. 169) introduced the concept that basal Michigan deposits interfingered with upper Marshall sandstones after he had made a comprehensive study of Michigan gas sands. He described the gas-bearing "Stray" sandstone of the Clare, Vernon and Leaton fields as grading laterally into the Napoleon sandstone, thus making the Napoleon sandstone stratigraphically higher in one area than another. Apparently at the same time, Hake (1938, p. 404) came to the same conclusion, stating that the Michigan "Stray" sands are fingers from the top of the Marshall or isolated lentils contemporaneous with parts of upper Marshall. According to Addison (1940, p. 1967), Michigan sediments were being deposited in one part of Isabella County before Napoleon sandstone deposition had ended in another part of the county 35 miles away.

Sufficient data are now available to justify the general acceptance of the views expressed by Hard and Hake on the gradational relationship of the Marshall and Michigan formations. Although there is an interfingering of the Marshall sandstones with the shales and dolomites in the west-east cross section *BB'* (Fig. 6) and the north-south cross section *AA'* (Fig. 4), this feature is best illustrated in cross section *BD* (Fig. 5) extending northeast from Oceana County into Crawford County. The end wells (1, 2, 8 and 9) in this cross section contain 120–150 feet of Marshall, whereas wells 3 and 4 have 235 and 295 feet, respectively. The cause of this great difference in thickness is a lensing of the upper sandstones, which is shown in the wells in the central part of the cross section. The interfingering of the upper part of the sandstone in the northeast corner of Lake County (well 4) with the dolomite and gypsum deposits of the Michigan formation in Wexford and Missaukee counties (wells 5, 6, and 7) illustrates the stratigraphic relationship of the Michigan "Stray" to the Marshall sandstone. Correlation of the sandstone beds overlying 60 foot of dolomite, shale,

and gypsum in Missaukee County with the thick Marshall section in Lake County is evident.

A similar relationship at the top of the Marshall formation is found in most of the western half of Michigan. As the change from Marshall sandstone deposition to Michigan dolomite, shale, and gypsum deposition was gradual, some of the thinner sandstones included in the Michigan formation may be isolated lentils deposited in the Michigan sea independent of any connection with the Marshall formation. Some of the higher and more discontinuous sandstones shown in the cross sections are probably of this character. It is extremely difficult to separate the sandstone beds completely surrounded by Michigan deposits from the thin fingers of sandstone continuous with the Marshall sandstones unless samples from closely spaced wells are available. Stearns and Cook (1932) attempted to differentiate the sandstones in the Michigan formation from those of the Marshall by differences in mineral composition, but were unsuccessful. The general area in which the Michigan "Stray" sands are mostly fingers from the top of the Marshall is west of central Roscommon County, western Gladwin and Midland counties, western Saginaw, Shiawassee, and Livingston counties.

Thickness.—The thickness of the Marshall sandstone varies appreciably in different parts of the state. The greatest thickness occurs in a well in west-central Ionia County in Sec. 16, T. 6 N., R. 8 W., where 305 feet of light gray to buff sandstone was penetrated. The upper 210 feet of this interval consists of fine- to medium-grained, buff sandstone and the lower 95 feet is a very fine-grained, gray to buff sandstone. Where the top and base of the formation are easily identified, the thinnest Marshall section is in a well in Newaygo County (well 3, cross section *BB'*, Fig. 6). The formation is only 130 feet thick at this locality. The upper 70 feet of the formation in this well consists of small- to medium-grained, buff sandstone which is underlain by 40 feet of fine- to medium-grained, light red sandstone. The basal 20 feet is composed of an upper 10 feet of fine-grained red sandstone and a lower 10 feet of fine-grained tan sandstone.

The thickness of the Marshall formation elsewhere in the western half of Michigan ranges from 130 to 305 feet. It is difficult to determine an average thickness for the formation, because the Marshall deposits interfinger with those of the Michigan. Basinward from the thick sections in southwestern Michigan, the sandstone ranges from 230 to 270 feet in thickness in an area extending northward from central Gratiot County, through eastern Isabella and western Mecosta counties, and thence into Osceola County. The places in which the fingers of Marshall sandstone into the Michigan deposits are best developed are adjacent to the area outlined. The Michigan "Stray" sandstone is thickest and occurs at most places in the area adjacent to the thickest section of Marshall sandstone. This feature is illustrated in cross sections *BD* (Fig. 5), *AA'* (Fig. 4) and *BB'* (Fig. 6). In areas containing the Michigan "Stray" sandstone, there is generally 150–180 feet of Marshall sandstone between the Coldwater shale and the lowest dolomite and shale of the Michigan formation. Overlying this interval of sand-

stone is the zone of interfingering Marshall and Michigan deposits which gives rise to the Michigan "Stray" sandstone. The thickness of the shale and dolomite separating the Michigan "Stray" sandstone from the main body of Marshall sandstone can be as much as 50 feet. The overlying Michigan "Stray" sandstone reaches a maximum of 70 feet in thickness. The total thickness of the sandstones, shales, and dolomites from the base of the Marshall to the top of the Michigan "Stray" rarely exceeds 300 feet. At most places it is about the same as the thickness of the Marshall sandstone in southwestern Michigan where no "Stray" sandstone is evident.

East of the interfingering Marshall and Michigan deposits, and west of the area in which the Coldwater-Marshall contact becomes indistinct, the thickness of the Marshall formation is remarkably uniform. The nine wells at the north end of cross section *AA'* (Fig. 4) illustrate the occurrence of the Marshall a few miles east of the eastern extent of well developed Michigan "Stray" sandstones. The thickness of the Marshall illustrated this cross section is 200 feet in Gladwin County. The formation thins gradually northward to 130 feet in Crawford County. The relationship of the thin Marshall formation in Crawford County to the thicker sandstones on the west is shown in cross section *BD* (Fig. 5). South of Gladwin County, in those restricted areas where the top of the Marshall is a definite stratigraphic horizon as it appears to be in eastern Michigan, and where the Marshall-Coldwater contact is easily recognized, the thickness of the Marshall formation averages approximately 200 feet.

In the southern part of the state, the Marshall formation thickens toward the south. This thickening is shown in the southernmost wells on cross section *AA'* (Fig. 4). An average thickness of 275 feet from Ottawa County to Jackson County is shown on cross section *GG'* (Fig. 10). The Marshall thickness in this area is equal to, and is generally greater than, that of any other locality in the state where the base of the formation can be clearly defined. This is important, as a general thinning of the Marshall formation southwest was described by Lane and Seaman (1909, p. 81) and has been referred to by other authors (Newcombe, 1933, p. 57; Ball *et al.* 1941, p. 241). These geologists compared the thickness of the Marshall formation in southwestern Michigan with the 500 feet of sandstone, shale, and interbedded red sediments in east-central Michigan, which in this report have been shown to be partly Coldwater in age. The reported 560 feet of Marshall sediments in northern Huron County (Lane, 1900, Pl. 1) also has led writers to the erroneous conclusion that the Marshall thins appreciably toward the southwest. It is shown in the discussion of the Coldwater-Marshall strata in northern Huron County that Lane overestimated the thickness of the Marshall formation in that area.

The only area of considerable extent west of central Michigan in which the Marshall formation is less than 200 feet in thickness extends from the drift-covered outcrop in Oceana County, eastward through central Newaygo County and into the western edge of Mecosta County. The thickness of the Marshall

formation ranges from 130 to 160 feet in the center of the area (wells 1, 2, and 3, cross section *BB'* Fig. 6). As shown by the cross section, there is very little sandstone above the lowest gypsum and shale of the Michigan formation. However, toward the margin of the area in northern and southern Newaygo County, fingers of "Stray" sandstone are present extending from the thicker Marshall sections surrounding the area of thin Marshall. North, east, and south of the area of thin Marshall, sandstone deposits thicken in a very short distance. The increase in thickness of the sandstone from Oceana County northward into Lake County is illustrated in cross section *BD* (Fig. 5). The thickening toward the south from Oceana County is equally as great. In the southwest corner of Newaygo County, 240 feet of sandstone is present, which is similar to that in Ottawa County shown in the western part of cross section *GG'* (Fig. 10).

Several important features of the Marshall formation are brought out in the foregoing discussion. There is a definite thinning of the Marshall from northern Midland County northward through Gladwin and Roscommon counties and into Crawford County. The Marshall increases in thickness from Clinton County southward into Jackson, Calhoun, and other counties in southwestern Michigan. The regional thickening from the north-central part to the southern part of the state amounts to 160 feet. A regional southward thickening of the Marshall is not evident in the western part of Michigan. In the area of interfingering Marshall and Michigan sediments in western Missaukee, Wexford, and Lake counties, the thickness of the sandstones with some interbedded shale is almost equal to that found in counties on the south. In Jackson, Calhoun, Barry, Eaton, and southern Ionia counties, the thick sections of Marshall sandstone are uninterrupted by dolomite and gypsum deposits and in only a few places by a thin gray shale. Elsewhere in central and western Michigan, excepting in an area in central Gratiot County, Isabella County, and eastern Mecosta County, the thick sandstone sections are generally interrupted by fingers of Michigan deposits. The area of the thick Marshall sandstone in southwest Michigan is much greater than elsewhere in the state. Thicknesses of more than 250 feet are present in the area from Jackson County in southern Michigan into Muskegon County on the western side of the state.

UPPER MARSHALL OF EASTERN MICHIGAN

The Marshall formation of the eastern half of the Southern Peninsula differs from that in the western part of the state in several ways. The absence of any uniform criteria for separating the Marshall from the Coldwater in the area is mentioned in the discussion of the Coldwater. There is, however, a marked lithologic change in the upper part of the Marshall formation in eastern Michigan. The upper 90–160 feet of sandstone is appreciably more coarse-grained and more poorly cemented than the lower beds. The sandstone is nowhere red, but may be tan, light gray, or white. Both the stratigraphic position and the litho-

logic character indicate that the sandstone corresponds with the Napoleon sandstone member of the Marshall formation.

The stratigraphic relationship and lithologic character of the Napoleon sandstone from western Gladwin County in the central part of the Michigan basin to the eastern margin of Arenac County are illustrated in cross section *FF'* (Fig. 5). The wells in Gladwin County on this cross section (wells 1, 2, and 3) are in an area in which the Marshall formation can be separated from the Coldwater formation and in which it can be divided into upper and lower members on a lithologic basis. Although east of Gladwin County a persistent lithologic basis for separating the Marshall from the Coldwater is absent, the Napoleon sandstone can be separated from the lower sediments. This medium-grained, loosely cemented sandstone ranges from 110 to 150 feet in thickness in the wells shown in cross section *FF'*. Coarse sand grains are commonly mixed with grains of smaller size near the base of this member.

Similar occurrences of Napoleon sandstone are found in most of the eastern Michigan counties. The sandstone has an average thickness of 120 feet and can be recognized eastward from Gladwin, Midland, and Saginaw counties to the drift-covered outcrop area.

The areal extent of the Napoleon sandstone westward as a separate lithologic unit is variable. It has been mentioned that the Marshall is divisable into members in parts of Clare, Isabella, Gratiot, Midland, and Clinton counties. The value of the Napoleon as a mappable unit is less in these counties due to its interfingering relationship with the Michigan formation.

No evidence was observed in the well samples from the eastern part of the state which indicates that the sandstones above the lowest dolomite, limestone, and shale of the Michigan formation are lateral extensions of Marshall sandstone. The Michigan sandstones in this area are commonly finer-grained and better cemented than the Napoleon sandstone. They are interbedded with shale, dolomite, and gypsum and are less than 20 feet thick at most places. The top of the Marshall in eastern Michigan, therefore, is an acceptable stratigraphic marker and generally can be used as a datum for structure mapping.

COLDWATER-MARSHALL STRATA IN NORTHERN HURON COUNTY

INTRODUCTION

The stratigraphy in northern Huron County is discussed separately because the lithologic character of the Marshall and upper Coldwater beds in this area is somewhat different from that elsewhere in the state. The two main problems are the correlation of the outcrops along the shore of Lake Huron and the location of the Coldwater-Marshall contact. A brief description of the outcrops is first given, followed by a correlation of the outcrops based on subsurface information. The regional dip is southwest in Huron County and the outcrops are described from west to east, or in general from the top of the Marshall formation to the

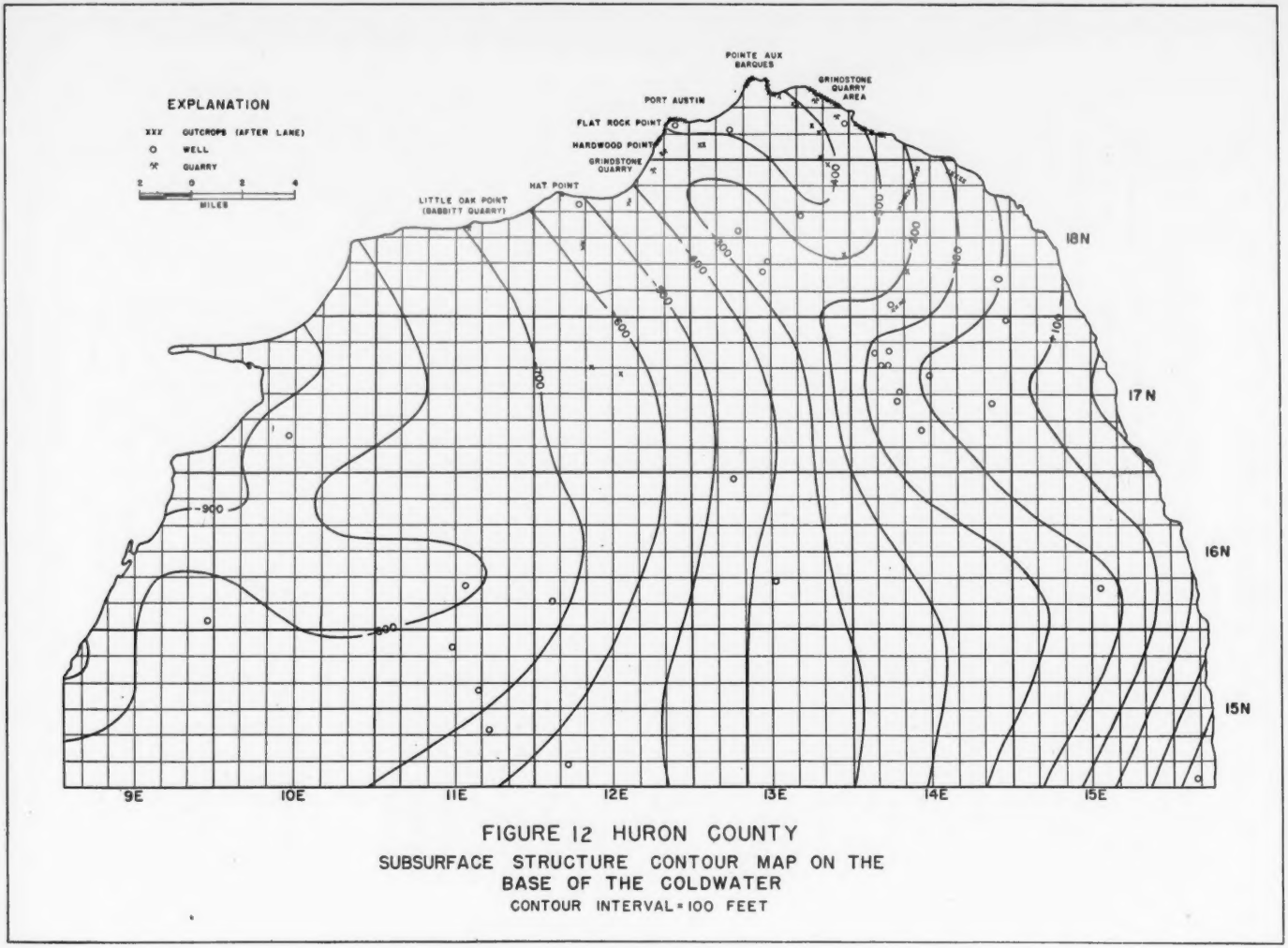


FIGURE 12 HURON COUNTY
SUBSURFACE STRUCTURE CONTOUR MAP ON THE BASE OF THE COLDWATER
CONTOUR INTERVAL = 100 FEET

FIG. 12.—Subsurface structure-contour map of Huron County, Michigan.

base. The outcrops are discussed in this sequence in order to start with known Marshall rocks and proceed to beds which are of questionable Marshall age.

OUTCROPS

The uppermost beds of undoubted Marshall sandstone crop out on the north and south sides of Rush Lake, inland from Little Oak Point (Fig. 12). The best exposure is in an abandoned quarry between an old east-west road and the present road in Sec. 15, T. 18 N., R. 11 E. Although the lower 5 feet of strata is covered with water, about 14 feet of medium- to coarse-grained, very friable sandstone, speckled throughout with limonite, is exposed in the quarry. With the exception of the top 3 feet of thin-bedded strata, the beds are massive and cross-bedded. Lane (1900, Pl. 1) assigned the strata at Babbitt quarry to the middle part of the Napoleon sandstone.

East of the Rush Lake exposures, the first outcrop of the sandstone along the shore line is at Hat Point in Sec. 7, T. 18 N., R. 12 E. Twelve feet of fine- to coarse-grained, cross-bedded sandstone is exposed. Streaks of small quartz pebbles and flakes of black carbonaceous material occur in the rock. The color ranges from buff to greenish gray. Lane (1900, p. 19) assigned this sandstone to the base of the Napoleon.

Two miles inland from Hat Point, about 10 feet of sandstone is exposed along Taft Drain in the NE. $\frac{1}{4}$ of Sec. 20, T. 18 N., R. 12 E. The rocks exposed range from very fine-grained, green sandstone to coarse-grained, tan sandstone. The different lithologic types grade into one another vertically and laterally. A small exposure of fine- to medium-grained, greenish tan, non-fossiliferous sandstone is found in the bed of the small creek near the center of Sec. 5, T. 17 N., R. 12 E.

East of Hat Point is an outcrop which was not available to the early geologists. The exposure is the result of grindstone quarry operations which began at this locality after Lane (1900) had completed his field work in Huron County. The quarry is southwest of Hardwood Point on both sides of the present highway in Sec. 2, T. 18 N., R. 12 E., and exposes about 9 feet of strata. The upper 7 feet is thin-bedded, grayish green, very fine-grained sandstone, but the lower 2 feet is more massive. The latter is underlain by a more massive sandstone, as indicated by the thick large slabs lying around the pit. There are small pebble zones an inch or two thick throughout the sandstone, but they disappear laterally over a distance of a few yards. There also are some larger individual pebbles scattered throughout the very fine-grained sandstone which was used for grindstones. Large fragments of brown, pebbly conglomerate which resembles peanut brittle candy are found on the north side of the road. Lane (1900, p. 19) applied the term "peanut conglomerate" to rock of identical appearance occurring near Grindstone City.

A few feet of very thin-bedded, fine-grained, greenish to reddish sandstone are exposed at Hardwood Point, one mile northeast of the grindstone quarry previously mentioned. The rock is lithologically very similar to the sandstone from which grindstones were cut. Winchell (1861, p. 80) noted that the sandstone

FIG. 12.—Subsurface structure-contour map of Huron County, Michigan.

at Hardwood Point contained fossils which are characteristic of the "Marshall group." The strata at this locality appear to have a northeast dip.

The shore of Lake Huron is barren of rock ledges from Hardwood Point to Flat Rock Point (Fig. 12). A medium- to coarse-grained, light gray sandstone crops out along the shore from Flat Rock Point to Port Austin. The sandstone is massive and cross-bedded and is ordinarily soft. There are many seams of small pebbles throughout this sandstone which disappear laterally. There are approximately 25 feet of sandstone exposed. At Broken Rocks, ½ mile west of Port Austin, the sandstone has been broken into huge blocks by joints which give the shoreline a very distinctive appearance. East of Broken Rocks the massive sandstone is succeeded by thin-bedded, greenish to reddish, fine-grained sandstone rising only a foot or two above the water. The fine-grained sandstone is the easternmost outcrop west of Port Austin. There is a great similarity between this sandstone and that at Hardwood Point. The sandstone is capped by a band of "peanut conglomerate" 8 inches thick.

Inland from Flat Rock Point, in the NE. ¼, NW. ¼ of Sec. 36, T. 19 N., R. 11 E., recent removal of 2 feet of top soil over an area of approximately 300 square feet has exposed fine-grained, tan to reddish tan, very thin-bedded sandstone in which a few fossils were found.

South of Port Austin, a hill rises above the surrounding country to the highest elevation in this part of Huron County. Although no bedrock was seen, slabs of sandstone are abundant over the entire hill. At the top of the hill the slabs consist of medium- to coarse-grained, grayish white to tan sandstone. Fragments of a fine-grained, green to tan sandstone are on the flanks of the hill.

The sandstone cliffs at Pointe aux Barques are the first outcrops east of Port Austin. These cliffs rise 19 feet above Lake Huron and are composed of sandstone very similar to that found west of Port Austin. It is massive, cross-bedded sandstone with grain sizes ranging from fine to coarse. The sandstone is light gray to buff, friable and porous. It occupies about ¾ mile of the shoreline in the vicinity of Pointe aux Barques. These beds appear to have a slight dip southwest which Winchell measured as 1½°.

Eastward from Pointe aux Barques no bedrock is exposed along the lake shore to the vicinity of Eagle Bay. Near the center of Sec. 23, T. 19 N., R. 13 E., the "grindstone" beds come to the surface. Lane (1900, p. 21) describes the interval from the base of the sandstone at Pointe aux Barques down to the grindstone beds as being composed of beds which "become gradually thinner and finer grained . . . until finally we have a little blue shale, and . . . narrow seams of calcareous sandstone covered with *Camarotaechia* (*Rhynconella*) *camerifera* and *Romingerina* (*Centronella*) *julia*." The fossil zone referred to by Lane is found on the north side of the east-west road, extending through the center of the E. ½ of Sec. 26, T. 19 N., R. 13 E. The rock containing these fossils is 3 feet of calcareous, well cemented, very fine-grained, gray to brown sandstone cropping out about 200 feet east of the intersection of this road and a north-south road extending through the center of the section.

East of Burnt Cabin Point in Sec. 23, T. 19 N., R. 13 E., the fine-grained, greenish sandstone which was quarried so extensively for grindstone purposes prior to 1900 crops out along the shore intermittently more than 2 miles. Lane (1900, p. 22) estimated this sandstone to be 25 feet thick. These beds occupy the shoreline more or less continuously until they grade downward into blue-gray shale in the shore cliffs in Sec. 30, T. 19 N., R. 14 E. (Fig. 13). It is at the top of this shale that Lane (1900, p. 22) placed the Coldwater-Marshall contact.

Immediately overlying the grindstone beds, according to Lane (1900, p. 21),

FIG. 13.—Interbedded sandstone and shale underlying "Grindstone" beds along shore of Lake Huron, Huron County, Michigan.

is a "peanut conglomerate." This conglomerate was not found in place either at the quarries or on the lake shore, but fragments are numerous and its position as described by Lane is not questioned.

The sandstone which was used as grindstone is a very fine-grained, greenish sandstone occurring in beds one inch to a foot in thickness. Large rounded quartz pebbles which caused the grindstone makers considerable trouble are scattered throughout most of the sandstone. The sandstone is moderately hard and the crushed samples show it to be somewhat argillaceous. All of the deeper quarries are now filled with water, but an examination of discarded quarried blocks from the sandstone suggests that there are no lithologic differences between the top and the bottom of the grindstone beds.

The only remaining exposures in Huron County which have been described

by other workers in connection with the outcrops described are those found along Willow River in T. 18 N., R. 14 E. The outcrops are more or less continuous from Huron City upstream through Sections 4 and 9, where alternating beds of sandstone and shale are exposed, with the sandstone predominating. Twenty-five feet upstream from the highway bridge at Huron City and 10 feet above the creek bottom is a very fossiliferous, fine-grained shaly tan sandstone.

Sand grain size and color has been emphasized in the discussion of the sandstones cropping out in northern Huron County. Excepting for these two features, there is little lithologic difference in the various sandstones. Neither the coarse nor the fine sand grains have frosted surfaces. The roundness of the grains varies slightly with the size, the coarser grains being more rounded than the finer. Most of the binding material is both argillaceous and ferruginous, although some zones in the sandstones are calcareous.

Thin sections were made of samples of sandstone collected at Hat Point, Pointe aux Barques, and at a grindstone quarry near Grindstone City. The mineral composition in these thin sections is almost identical. Quartz, chert and fragments of mica schist are the main components of the sandstones. Approximately 95 per cent of the rock fragments in each slide is composed of quartz and chert. Tourmaline and zircon occur in small amounts. A low feldspar content is characteristic of the rocks. A few fragments of orthoclase and plagioclase feldspar are present in the sandstone, but their abundance does not surpass that of biotite, chlorite, sericite, apatite, or ilmenite.

CORRELATION OF OUTCROPS

The correlation of the outcrops described has been a subject of contention since the publication of Winchell's original description (1861, pp. 80–83) of the strata cropping out along the north shore of the county. Rominger (1876, p. 75) objected to Winchell's idea that stratigraphically the sandstones were successively lower from west to east along the shore. He believed that most of the sandstones were at about the same stratigraphic level.

The most detailed geologic study in Huron County was made by Lane (1900). After a thorough investigation of the data from water wells and an examination of practically all of the outcrops in Huron County, Lane expressed the opinion that Winchell's original interpretation of the relationship of the sandstone beds cropping out along the shore of Lake Huron was correct. He (Lane, 1900, Pl.1) compiled a detailed stratigraphic column showing 560 feet of Marshall strata, of which 300 feet is classified as Napoleon.

Because of the absence of a stratigraphic marker in the Marshall and Coldwater sediments which could be used as a horizon for mapping the structure of this area, Lane was greatly handicapped in securing accurate data on the amount of folding of these beds. Although subsurface data are still not plentiful in Huron County, a sufficient number of wells have now been drilled through the base of the Coldwater to permit a much better understanding of the succession of beds

in the Marshall and Coldwater formations. A solution to the northern Huron County stratigraphic problem based on subsurface data almost entirely is presented in the following paragraphs. It differs from both the Winchell-Lane interpretation and the Rominger concept, but it is a compromise of the two.

The problem is primarily one of structure, as correlation of the individual beds is much less difficult when the structure is understood. The structural contours shown in Figure 12 are on the base of the Coldwater formation, which rests on the Sunbury black shale in Huron County. The largest structural anomaly in this area is the anticlinal fold and associated syncline in the northernmost part of the county. The elevation of the base of the Coldwater on the crest of the anticline is more than 125 feet above the elevations on the northeast and southwest. The northwest extension of the fold into Saginaw Bay is indicated by the increasing influence of the fold on the structure contours from southeast to northwest. It appears certain that the fold must involve some of the shoreline outcrops. The syncline on the northeast can not be outlined as accurately as the anticline due to insufficient data. Its presence is unquestioned, however, as the dip on the northeast flank of the anticline must revert to the southwest regional dip in this area. Lane (1900, p. 92) recognized a northeast dip between Hardwood Point and Flat Rock Point, but he minimized the importance of the dip. Structural control points in the synclinal area are obtained from very incomplete data of old Berea brine wells. In a well very close to Flat Rock Point in Sec. 25, T. 19 N., R. 12 E., and in a second well approximately 2 miles east in Sec. 29, T. 19 N., R. 13 E., the Berea sandstone was penetrated at depths greater than 500 feet below sea-level. As the average thickness of the Sunbury, which separates the Berea from the Coldwater, is approximately 100 feet, the base of the Coldwater is between 400 and 460 feet below sea-level. Another abandoned Berea brine well near Grindstone City, in Sec. 25, T. 19 N., R. 13 E., apparently is on the northeast flank of the syncline. The base of the Coldwater is approximately 320 feet below sea-level in this well.

The effect of this anticline and syncline on Winchell's and Lane's correlation of the outcrops along the shoreline is obvious. There are four general outcrops of coarse-grained sandstone along the north side of Huron County (Fig. 14): (1) near Little Oak Point in Sec. 15, T. 18 N., R. 11 E., (2) Hat Point in Sec. 7, T. 18 N., R. 12 E., (3) Flat Rock Point to Port Austin, and (4) Pointe aux Barques. The coarse-grained sandstone at Flat Rock Point-Port Austin appears to be correlative with the sandstone of identical character at Pointe aux Barques. This sandstone occurs approximately 1,000 feet above the base of the Coldwater and is 25 feet thick. Shale, sandy shale, and the fine-grained, greenish sandstone from which grindstones were cut underlie this coarse-grained sandstone. The grindstone beds in the vicinity of Grindstone City are the same strata which were quarried southwest of Port Austin in Sec. 2, T. 18 N., R. 12 E. Lane's (1900, Pl. 1) measured interval of 40 feet between the base of the Pointe aux Barques sandstone and the top of the grindstones is not questioned. The fine-

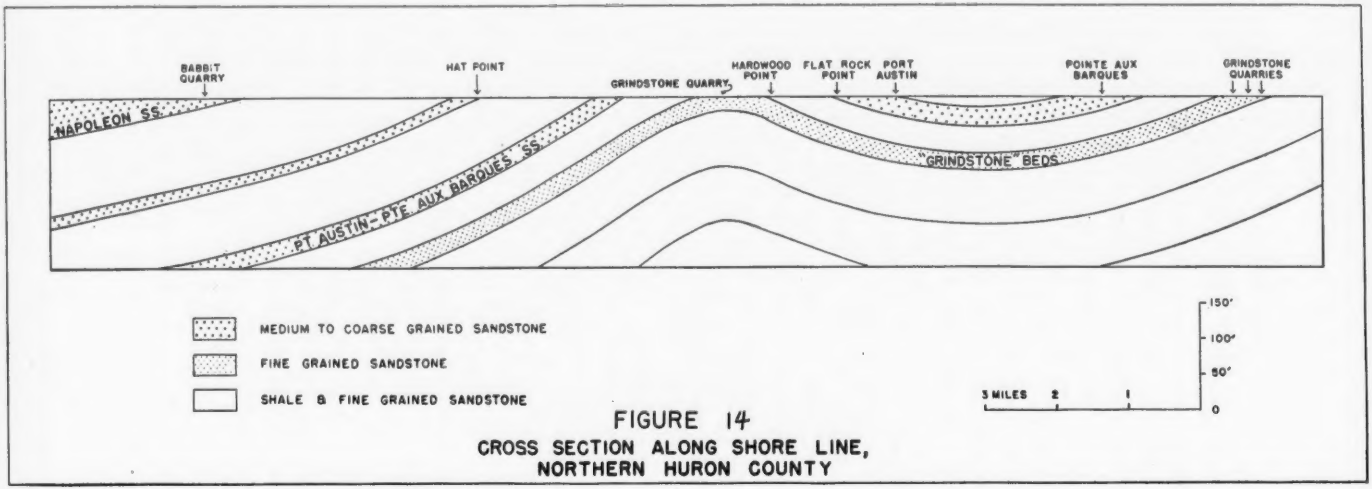


FIGURE 14

CROSS SECTION ALONG SHORE LINE,
NORTHERN HURON COUNTY

FIG. 14.—Cross section along shoreline, northern Huron County, Michigan.

grained sandstone with interbedded shale cropping out at Hardwood Point is characteristic of the zone between the coarse-grained sandstone of Pointe aux Barques and the main grindstone zone.

If these correlations are correct, the 95 feet of sediments in Lane's stratigraphic column (1900, Pl. 1) between the Port Austin coarse-grained sandstone and the Pointe aux Barques coarse-grained sandstone is a repetition of beds due to folding. The question then arises whether the coarse-grained sandstone at Hat Point west of the anticline is correlative with the Flat Rock-Port Austin-Pointe aux Barques sandstone as Rominger (1876, p. 74) suggested. Data obtained from a well recently drilled within a mile of Hat Point show the improbability of this correlation. The base of the Coldwater lies 520 feet below sea-level in this well, or approximately 100 feet lower than at Port Austin and Pointe aux Barques. The surface elevation along the north shore of the county where the outcrops under discussion occur is approximately 600 feet (water level = 581 ± feet). The sandstone at Hat Point is therefore about 1,100 feet above the base of the Coldwater, whereas the Port Austin-Pointe aux Barques sandstone is 1,000 feet above this datum. It appears that Lane was correct in separating the Hat Point sandstone from the Port Austin sandstone. His stratigrapnic column (Lane, 1900, Pl. 1) shows an interval of 85 feet between the two.

The most western exposure of these coarse-grained sandstones in northern Huron County is in the abandoned Babbitt quarry near Little Oak Point in Sec. 15, T. 18 N., R. 11 E. There is general agreement that this sandstone belongs to the Napoleon. Although control for structural contours is meager in this area, the base of the Coldwater is estimated to be about 700 feet below sea-level, and as the elevation of this outcrop is approximately 600 feet above sea-level, the sandstone is slightly more than 1,300 feet above the base of the Coldwater.

Lane (1900, p. 19) assigned a thickness of 300 feet to the Napoleon sandstone on the assumption that the drift-covered outcrop extended from Babbitt quarry to Hat Point, a distance of nearly 4 miles. He wrote, however, "the thickness of 300 feet above mentioned is not obtained directly, and may include, as did Winchell, some of the bluish micaceous sandy shales which we have estimated in the overlying group." It is apparent from the subsurface information now available that the thickness of the Napoleon sandstone rarely exceeds half of this amount. Lane (1900, p. 19) noted a thickness of Napoleon of 135 feet at Bayport in Sec. 5, T. 16 N., R. 10 E., and of 110 feet at Pigeon in Sec. 11, T. 16 N., R. 10 E. Other wells penetrating a complete section of Napoleon in Huron County show an average thickness of 120 feet. Until a well is drilled which proves a great thickening of the upper Marshall sandstone in the area between Babbitt quarry and Hat Point, it appears most logical to accept the available subsurface data on the thickness of the Napoleon sandstone in Huron County.

An interpretation of the stratigraphy along the north shore of Huron County based largely on subsurface data may be summarized as follows. There are three coarse-grained, cross-bedded, poorly assorted sandstones. The lowest is the 25

feet of sandstone cropping out between Flat Rock Point and Port Austin, and at Pointe aux Barques. This sandstone is 1,000 feet above the base of the Coldwater. The second sandstone, lithologically identical, occurs 80–100 feet above the lowest sandstone. There is 15 feet of this sandstone exposed at Hat Point. The third and uppermost coarse-grained sandstone is the Napoleon, which is exposed near Little Oak Point. The thickness of the Napleon sandstone is assumed to be 120 feet with its base 1,200 feet above the base of the Coldwater. Shale, sandy shale, and fine-grained sandstone separate the three coarse-grained sandstones. The total thickness of the section from Little Oak Point to the base of the grindstone beds at Grindstone City is about 350 feet.

COLDWATER-MARSHALL CONTACT

Correlation of the strata from Little Oak Point to Grindstone City in Huron County with the Marshall formation elsewhere in the state has been accepted since Winchell's original study. It has been demonstrated that it is extremely difficult to separate the Marshall from the Coldwater in the eastern part of the Southern Peninsula on subsurface data. The value of a separation based on the present surface information is questionable. In order to include all of the sandstones from Little Oak Point to Grindstone City in the Marshall formation, it is necessary to assume that the Coldwater is less than 1,000 feet thick in northern Huron County. As previously noted, however, a regional thickening of the Coldwater occurs from the west to the central part of the state and a thickening of the Coldwater-lower Marshall interval toward the east takes place in Arenac and Iosco counites. A thickening of the Coldwater-lower Marshall interval northeastward from Tuscola County also is indicated by a comparison of wells in Tuscola County with those in western Huron County. Wells 3, 4, and 5 (cross section *CC'* Fig. 7) in Tuscola County show a combined Coldwater-Marshall thickness of 1,225–1,250 feet including approximately 110 feet of Napoleon sandstone. In Huron County this interval is 1,325 feet in wells in Sec. 4, T. 15 N., R. 11 E., and in Sec. 28, T. 17 N., R. 10 E., with the thickness of the Napoleon remaining constant.

The well samples available to the writer are inadequate for accurate tracing of the coarse-grained sandstones of northern Huron County southwest into Tuscola County, where they lens out or become fine-grained. A well in southern Huron County in Sec. 32, T. 15, T. N., R. 12 E. (well 6, cross section *CC'*, Fig. 7) is the northeasternmost well in this area from which samples are available through almost the entire Coldwater-Marshall sequence. The lowest medium- to coarse-grained sandstone in this well is about 950 feet above the base of the Coldwater. It probably is the Pointe aux Barques-Port Austin sandstone, which is estimated to be 1,000 feet above the base of the Coldwater in northern Huron County.

In view of the fact that no reliable means for separating the Coldwater from the lower Marshall deposits have been recognized in this study, it is impossible to state that the thickening of the Coldwater-Lower Marshall strata eastward

into Huron County is limited solely to beds of Marshall age or to beds of Coldwater age. It seems unlikely, however, that the Coldwater in northern Huron County is less than 1,000 feet thick. Thicknesses greater than 1,000 feet occur throughout central Michigan from Kalkaska County to Jackson County and the Coldwater formation should thicken eastward toward the sandy, near-shore facies. It appears advisable to refer to the strata cropping out along the shore of Lake Huron eastward from Hat Point as Coldwater-lower Marshall until further information is available.

MICHIGAN FORMATION

The Michigan formation consists of the beds of shale, limestone, dolomite, gypsum, anhydrite, and sandstone that overlie the Marshall sandstone. Basal Michigan sediments are generally gray shale or gray to brown dolomite, although gypsum and anhydrite beds may be only a few feet above the Marshall sandstone in the western part of the state.

The most distinctive rocks of the formation are the gypsum and anhydrite. They occur throughout the entire Michigan strata in varying stratigraphic positions and amounts. Although in some places well samples representing a vertical distance of 40 feet are composed mostly of gypsum, it is difficult to trace any particular bed laterally for more than a few miles. The gypsum commonly grades laterally into shale and occurs at most places interbedded with shale. Gypsum and anhydrite are most abundant in the lower part of the formation (Newcombe, 1933, p. 57) and are most common in the western part of the state.

A bed of brown crystalline dolomite in the lower part of the formation has been frequently used as a stratigraphic marker in central Michigan (Hard, 1938, p. 136). Hard (1938, p. 137) noted that there is very little sandstone above this dolomite, but below the bed at varying distances is the "Stray" sandstone.

Although not a common feature of the Michigan formation, beds of oölitic limestone were penetrated in a well in Sec. 33, T. 25 N., R. 3 W., in Kalkaska County, and in a second well in Sec. 35, T. 16 N., R. 3 E., Bay County. Elsewhere the limestones of the Michigan formation are gray to buff, very fine-crystalline rocks which are dolomitic at many places.

The thickness of the Michigan formation varies considerably over the state. Newcombe (1933, p. 58) wrote, "The formation may be locally absent but generally it is from 50 to 550 feet thick." Hard (1938, p. 136) reported thicknesses ranging from 250 to 400 feet in the central part of the state. According to Bergquist (1938, p. 49), the formation generally thins toward the margin of the Michigan basin.

AGE AND CORRELATION

Winchell (1870) terminated his publications on the "Marshall group" with an extensive discussion of the age and correlation of the strata. In this report he included an excellent review of publications pertaining to the subject as well as definitely stating his beliefs about Marshall "equivalents" elsewhere in the

United States. After listing 416 species of fossils from the Marshall "and its supposed equivalents," and indicating the states in which they are found, he (Winchell, 1870, pp. 396–97) concluded,

> With such an extended network of identifications, and with long lists of representative species which I forbear to cite, I believe it will be admitted that the several formations brought under comparison must have been accumulated in one geological period. Let it now be distinctly stated what are the formations which are thus synchronized. They are as follows:
>
> 1. The Marshall Group of Michigan.
> 2. The Gritstone and Waverly series of Ohio, down to the Chocolate Shales.
> 3. The Goniatite Limestone of southern Indiana, and its equivalent sandstone in northern Indiana.
> 4. The Kinderhook Group of Illinois.
> 5. The Yellow Sandstone series of Iowa, at least down to the bluish sandy shales.
> 6. The series known in Missouri as the Chouteau Limestone, the Vermicular Sandstone and Shale, and the Lithographic Limestone.
> 7. The Silico-bituminous Shales at the base of the Silicious Group of Tennessee.

Winchell (1870, p. 415) stated that the age of these strata is the "Upper part of Catskill Group including 'Carboniferous' conglomerate and 'Chemung' conglomerate."

Winchell's correlation of the Marshall with Kinderhook strata has been generally followed by Michigan geologists (Lane, 1895, p. 19; Lane and Seaman, 1909, p. 79; Smith, 1912, p. 29). Perhaps the greatest deviation from Winchell's suggested correlations is shown in a correlation chart by Newcombe (1933, p. 50). The latter places the Coldwater and Marshall strata of Michigan and the upper part of the Waverly of Ohio in the Osage group, whereas the Rockford and Chouteau are shown to be of Kinderhook age. Ballard (1938, p. 1521) repeated this correlation in his Mississippian correlation diagram for central United States.

A copy of the first revision of the Geological Society of America "Mississippian Correlation Chart" (dated April 10, 1945) was made available to the writer by J. M. Weller. Coldwater and lower Marshall strata are shown on this chart in the upper part of the Kinderhook series with the Napoleon sandstone (upper Marshall) in the basal part of the Osage group. The Rockford limestone of Indiana, the Chouteau limestone of Missouri, the lower part of the Cuyahoga formation of the Waverly group of Ohio, and the larger part of the Coldwater shale are shown in approximately the same stratigraphic position in the upper Kinderhook series.

G. M. Ehlers, paleontologist at the University of Michigan, noted a similarity of some goniatites in the Marshall sandstone to certain species in the Rockford limestone of Indiana. He recently sent some of these Marshall specimens to A. K. Miller at the State University of Iowa for identification, as Miller (1935, pp. 434–35) had previously suggested that the Marshall was correlative with the Rockford and was Kinderhook in age. In a letter dated April 17, 1947, to Ehlers, Miller wrote that "the Marshall sandstone goniatites are so close to those of the Rockford limestone that the two formations are almost certainly correlative."

As the Rockford limestone is the name since given to the "Goniatite group of

southern Indiana" referred to by Winchell, this confirms the correlation made by Winchell in 1870. There seems little doubt that the Marshall formation is Kinderhook in age and should be correlated, in part at least, with the Rockford limestone and its equivalents in other states.

STRUCTURAL GEOLOGY

The base of the Coldwater formation is the youngest stratigraphic surface in Michigan on which structural contours can be drawn with accuracy over the greater part of the Lower Peninsula. The top of the Coldwater lends itself to this purpose in the west half of the state, but not in the east half, due to the indefinite Marshall-Coldwater contact. The top of the Marshall can be contoured accurately in the east half of the state but not in the west. Lateral lithologic changes cause the beds younger than Marshall to possess no well defined stratigraphic marker that is of value for regional mapping, although a few of these younger beds provide satisfactory markers in some parts of the state.

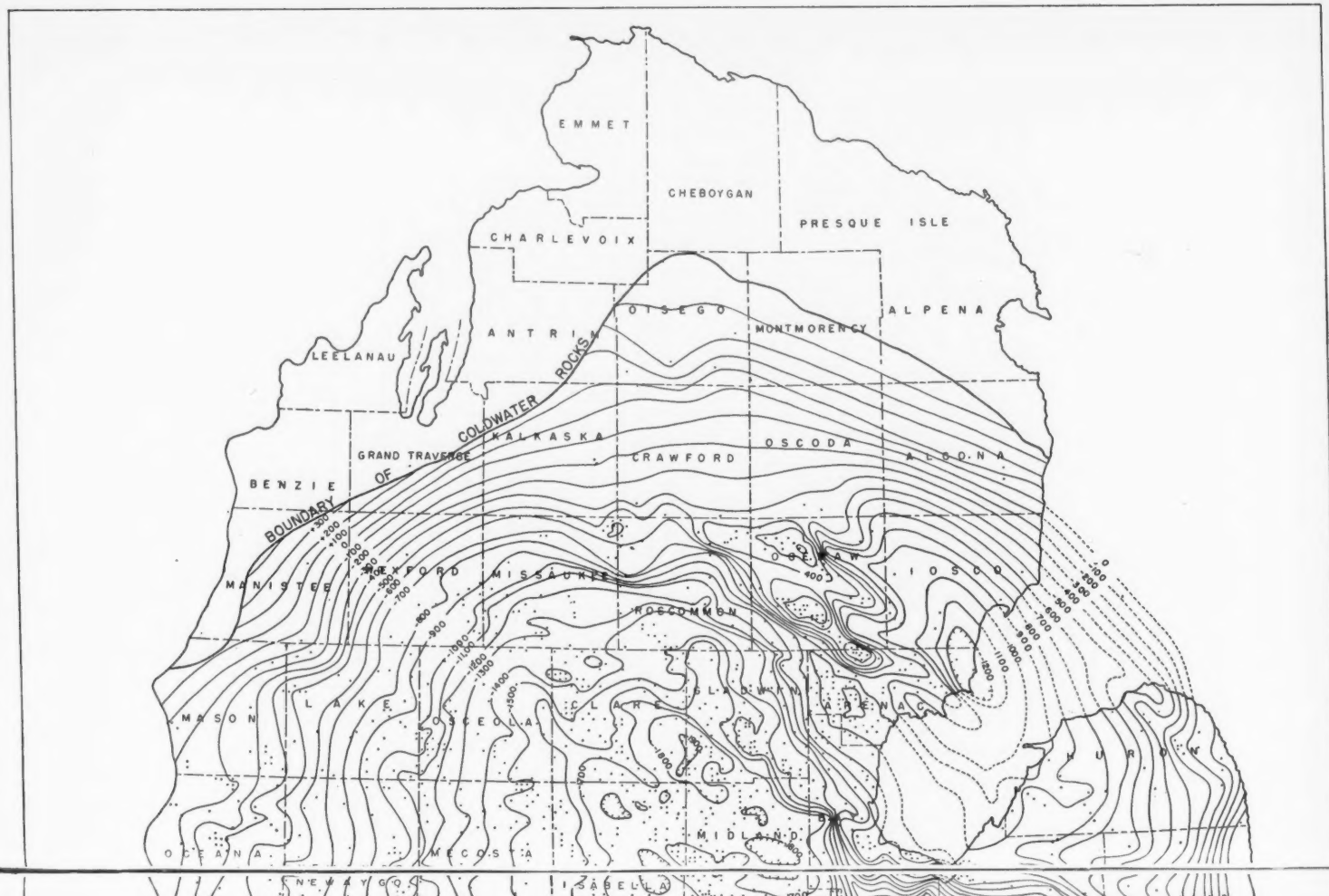
The structure of the rocks in the Southern Peninsula of Michigan at the base of the Coldwater formation is shown in Figure 15. Although the maximum structural relief exhibited on this surface approaches 2,700 feet, this figure does not represent the total relief originally, as older beds continue to rise beyond the limits of the Coldwater formation around the margin of the basin.

Regional dip into the center of the Michigan basin on the base of the Coldwater averages 20–25 feet per mile. Variations in dip both greater and smaller may be measured in almost any part of the state.

As shown in Figure 15, the deepest part of the structural basin lies in the southern Clare-Gladwin County area. Reflection of the structure in older beds by the base of the Coldwater is evident in the comparison of Figure 15 with structure-contour maps based on lower stratigraphic units. Cohee and Underwood (1945) show the deepest part of the basin, as revealed by structure contours on top of the Dundee-Rogers City sequence, to be in the almost identical area. In a study of the Salina and Bass Island rocks in Michigan, Landes (1945) designates this same area as the center of the basin.

The largest anticline contained within the limits of the Michigan basin is the Howell anticline trending northwest through Livingston County in the southeast part of the state. The structure may be described as an asymmetrical anticline plunging northwest with faulting on the steeper southwest side. This faulting has been described by Newcombe (1933). Cohee and Underwood (1945) report the recognition of a fault in a well located on the anticline in the central part of Livingston County. The maximum elevation of the base of the Coldwater on the Howell anticline amounts to 770 feet above sea-level near the center of Livingston County. The minimum elevation of this horizon in the vicinity of the structure may be taken as 1,000 feet below sea-level.

With the exception of the Howell anticline, the larger structural irregularities of the Michigan basin seem to be confined to the northeast part of the Southern


EMMET
CHEBOYGAN
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ALPENA
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COLDWATER ROCKS
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
BOUNDARY OF
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
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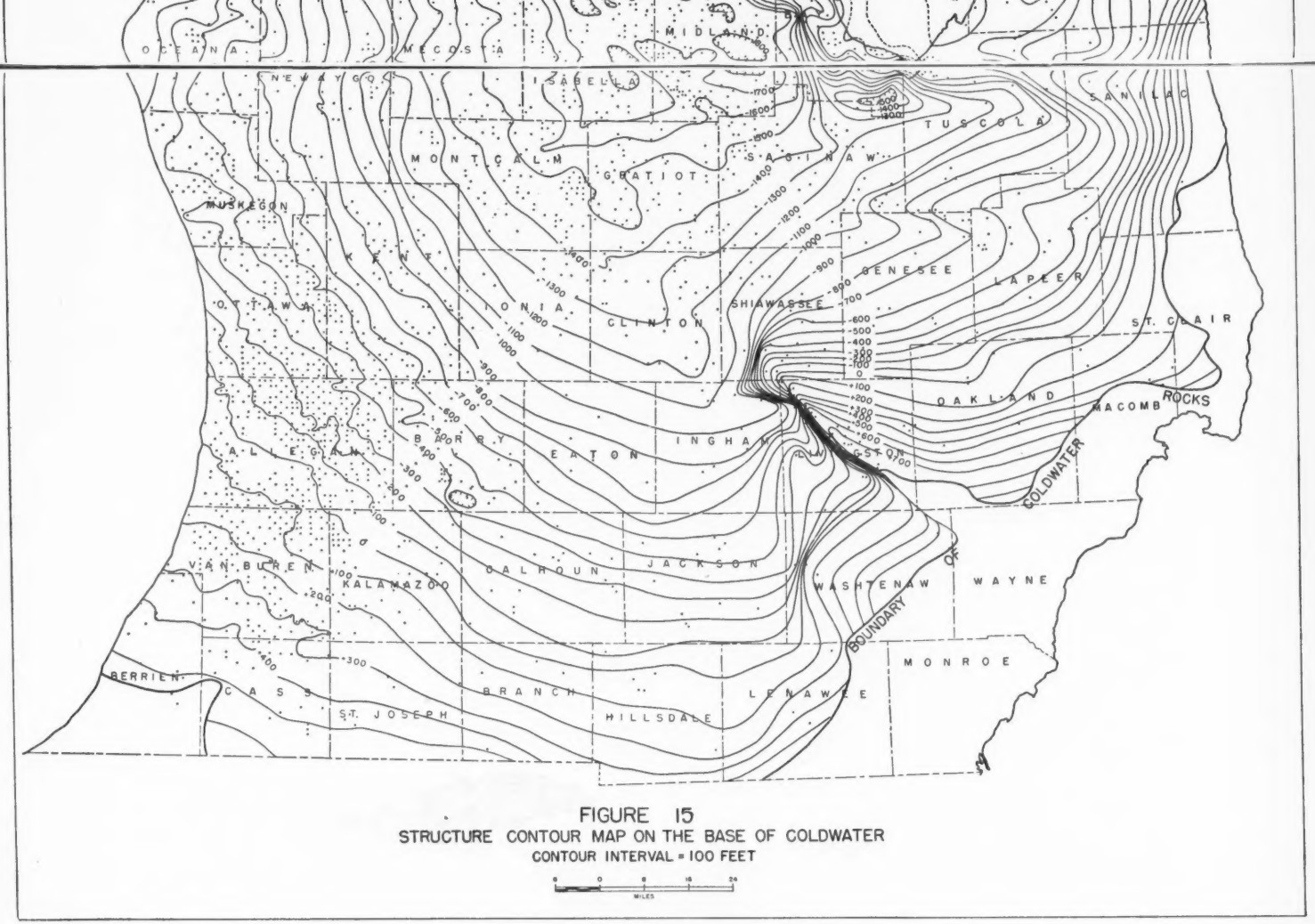

FIGURE 15
STRUCTURE CONTOUR MAP ON THE BASE OF COLDWATER
CONTOUR INTERVAL = 100 FEET

Fig. 15.—Structure-contour map of base of Coldwater formation.

Peninsula, especially in the vicinity of Saginaw Bay. From the east-west trending syncline in Tuscola County north to Oscoda County the beds have been folded appreciably and the general basin character of the rocks is greatly obscured. Three northwest-southeast anticlinal trends are recognized in Ogemaw and Arenac counties in *en échelon* arrangement. Dips as steep as 200 feet per mile are encountered locally. Closure on the higher parts of these folds may be found to reach 175 feet. Other structurally high areas of less definite outline and magnitude are found in Bay and Tuscola counties immediately south of Saginaw Bay.

Saginaw Bay itself presents an area in which speculation as to structure is most interesting, especially to the petroleum geologist. Anticlinal trends from the northwest in Arenac County should extend southeastward into the bay. The beds on the north limb of the Bay-Tuscola syncline continue to rise on the north with no indication of a dip reversal. This reversal and the resulting anticline must occur under the bay. It thus appears possible that the structure of the rocks underlying Saginaw Bay is more complicated than indicated on earlier maps.

The largest, most definite fold trending east and west in the state is the syncline occupying central Tuscola County and southeast Bay County. It is bounded on the north by an anticlinal ridge of approximately the same extent and direction. Closure of the contours on the west end of the syncline appears to be the most logical interpretation of structure on the base of the Coldwater formation, although structure maps on lower formations do not exhibit this closure.

The larger folds in the central part of the basin exhibit a general northwest-southeast trend. Closures approaching 150 feet are shown on the base of the Coldwater in this area. Other anomalies in the structural basin of Michigan are of more indefinite size and trend. They are distributed in an apparently unrelated arrangement throughout western and southwestern Michigan, usually appearing as local variations in direction of the 100-foot contours (Fig. 15). Closure of a contour around the structures, as in the northwest corner of Barry County, depends on the stratigraphic horizon on which the contours are based, as well as the number of control points available.

HISTORICAL GEOLOGY

COMPILATION OF EVIDENCE

A geologic history of Marshall time can be constructed from a consideration of the following pertinent information.

1. *Character of Coldwater depositional basin.*—The Coldwater basin of deposition was an area of marine sedimentation in which mud and carbonate material were being deposited in the deeper and quieter waters covering the western part of Michigan. In the eastern part of the state, mud and coarser clastics accumulated, indicating that the area was much nearer the shore of the Coldwater sea. The relatively uniform lithologic character of the Coldwater sediments from bottom to top in any area indicates that from the beginning to the end of Coldwater time conditions remained fairly uniform excepting in the extreme near-shore area in the east.

2. *Absence of unconformity between Coldwater and Marshall strata.*—It is emphasized in the discussion of the Coldwater formation that the source of the sediments during Coldwater time was at the east and lower Marshall deposition was so similar to that of the upper Coldwater that the accumulation of sediments in the eastern part of the state must have been continuous from Coldwater into Marshall time. Although in the western part of Michigan there is generally a marked change from Coldwater shale to Marshall sandstone, this change in sediments is largely an increase in the grain size of clastics and does not indicate an unconformity.

3. *Lithology of Marshall sediments.*—The sandstones and siltstones of the Marshall apparently were deposited in a shallow sea which frequently was disturbed in its entire area by waves and currents. The Marshall sediments are generally fairly well sorted locally, but lateral gradations in grain size are common throughout the sandstones. Areas near the center of the state, in which gray and red silt accumulated, were probably places in which there was less agitation of the water due to the greater depth.

Red sediments were carried into the Marshall sea during early Marshall time from the land areas on the east and west. It is probable that by the middle of Marshall time, very little red sediment was coming into the depositional area. The fine red silts brought in during early Marshall time were intermittently shifted around over the sea floor in some areas in the west in Michigan throughout later Marshall time.

4. *Present areal distribution of redbeds in Marshall formation.*—It is the writer's belief that the present areal distribution of redbeds in the Marshall formation has little bearing on the depositional history. The red colors are absent near the outcrops of the formation in southern and eastern Michigan and in the areas adjacent to the large anticlines in Shiawassee, Bay, and Arenac counties. This fact leads to the hypothesis that the red color has been destroyed by reduction and subsequent leaching where the beds are relatively near the surface, therefore, that the redbeds were originally much more widespread. If this thesis is correct, the present areal distribution of red color is due to processes in operation after the present structure of the Michigan basin was established.

5. *High feldspar content of sandstone in southwestern Michigan.*—The high feldspar content of the sandstones in southwestern Michigan is probably the best indication of a western source of sediments during Marshall time. It is very improbable that these feldspars came from the east as the feldspar content in the sandstone of eastern Michigan does not equal that of the sandstones on the southwest. The determination of a western source of sediments during Marshall time is not an entirely new concept, nor is it based solely on the petrographic studies described in this report. Stearns (1933) made a study of the minerals of the Marshall sandstone and concluded that the sandstones in western Michigan were closer to their source than those in eastern Michigan were to their source.

6. *Absence of thinning of sandstone on south and west, excepting in local areas, and thinning toward north-central part of state.*—The variations in thickness of

the sandstone strata do not offer much information regarding the depositional area. The beds of sandstone do not reflect the basin-like character of the area of deposition as do the Coldwater sediments. The thickest sandstones occur near the western, southern, and eastern margins of the present basin, but the sandstones in the west-central part of the basin are almost as thick. Irregularities in thickness of sandstones are to be expected, as less sand would accumulate in topographically high areas in a shallow sea than in adjacent lower areas. The area of thin Marshall in Oceana and Newaygo counties probably was relatively high on the floor of the Marshall sea. The area of thin Marshall in north-central Michigan is interpreted as an area of regional thinning toward the north, as the Marshall gradually decreases in thickness toward this area from the center of the state.

7. *Absence of any uniform and widespread basis for dividing Marshall formation.*—The impossibility of dividing the Marshall formation into two members is mentioned here to emphasize the opinion that the 130–300 feet of sandstone and siltstone accumulated under approximately the same conditions throughout the greater part of the state. Local influences, such as the topography of the sea floor, caused differences in sedimentation in some areas.

8. *Nature of Marshall-Michigan contact.*—The interfingering of the sandstones of late Marshall time with the shales and dolomites characteristic of the Michigan formation in the western half of the state is interpreted as indicating the absence of an unconformity between these two formations. Although an interfingering relationship of the Marshall and Michigan deposits is not evident in eastern Michigan, the two formations are considered to be conformable.

9. *Type of deposits in Michigan formation.*—The type of deposits in the Michigan formation are of particular importance in developing a history of Marshall time. The gypsum, anhydrite, limestone, and dolomite interbedded with gray shales and siltstones which overlie the Marshall formation are indicative of a change in climate and of a change in the conditions of deposition.

SEQUENCE OF EVENTS

The sea in which Coldwater sediments were deposited was of large extent. The area receiving the sediments was a large marine area with coarser clastics deposited in the near-shore area on the east and finer clastics and carbonates deposited farther seaward, away from the eastern source.

Marshall time was introduced by crustal movements both in the basin area and in the adjacent land areas, particularly on the west. The crustal movements resulted in the gentle uplift of granitic rocks in the Wisconsin Highland area, which then became an important source of sediments for the Michigan basin for the first time during the Mississippian epoch. The first sediments from this area to reach Michigan were fine-grained, red and buff sands which were deposited on the Coldwater shales. This change in the type of sediments being deposited in western Michigan marks the beginning of Marshall deposition.

In the eastern part of the state there was no sudden change in the type of deposits as the lower Marshall sediments were from the same source and of the same lithologic character as the near-shore facies of the Coldwater formation. The presence of conglomerate and coarse sandstone beds in the upper Coldwater-lower Marshall sediments probably signifies a gradual rise of the land surface on the east, resulting in a westward movement of the eastern shoreline of the sea. Throughout Marshall time the basin of deposition was becoming smaller and smaller due to the elevation of the surrounding land areas. This was accompanied by increasing aridity.

By the middle of Marshall time what had previously been a large depositional basin throughout Coldwater time, was a shallow-sea area with an irregular floor which was subject to wave and current action. The granitic rocks on the west continued to rise and most of the streams flowing eastward from this area were subject to frequent changes in volume and velocity as are the streams characteristic of arid and semi-arid regions. The coarsest material was deposited between the granitic area and the western margin of Michigan, but medium- and fine-grained sands were carried to that part of the Marshall sea covering the Southern Peninsula.

Near the middle of Marshall time the part of the Laurentian upland which had been the eastern source of Coldwater and lower Marshall sediments began to rise. This area was somewhat unstable throughout the Mississippian. The medium and coarse sands carried from the pre-Cambrian rocks of the Laurentian upland were deposited in eastern Michigan at the beginning of the Napoleon sandstone deposition. During the remaining Marshall time, medium-grained sands and some fine-grained sands were brought into the Marshall sea from the east and west. These sands were shifted about and deposited over the sea floor, with the thickest accumulations in the low areas and the thinnest on the topographically high areas.

Continued aridity, and evaporation of the shallow sea waters, resulted in further restriction of the Marshall sea. By this time it is probable that the sea was at least intermittently isolated from the ocean. The determination of the exact time that the first isolation of the Mississippian sea covering Michigan took place is difficult. It is possible that the separation accompanied the uplift of the area east of Michigan, which started the deposition of the Napoleon sandstone in the eastern part of the state.

Marshall deposition did not end simultaneously over the state. The first deposits of the Michigan formation accumulated in the quieter areas of the sea at the same time that Marshall sands were still being deposited in less quiet waters. It is possible that by this time an environment of great aridity existed over both the depositional area and the adjacent land areas. Streams which had been bringing sands into the state from the east no longer were able to carry anything but the finest clastics.

The Wisconsin Highland on the west continued to be drained by streams of

the torrential type, which were diminishing in number. They carried sand into the depositional area intermittently during the initial stages of deposition of the Michigan formation. The sand was spread out and deposited in an interfingering arrangement with the shale, dolomite, and gypsum deposits typical of the Michigan formation. Finally, the volume of the streams from the west was so reduced that they were unable to carry sand into the state. Mud and precipitates became the primary deposits throughout the Southern Peninsula, and Marshall time had come to an end.

The Marshall formation is thus seen to include the sediments which accumulated during the evolution from a large epicontinental sea surrounded by low land areas to a much smaller, shallow sea in which desiccation took place. Lane (1895, p. 19) summed up the significance of the Marshall formation by stating that "it marks the time at which the geological history of Michigan switches off from that of adjacent states and pursues its individual and peculiar course."

OIL AND GAS

Although the Michigan "Stray" sandstone is the largest natural-gas reservoir in Michigan, no commercial production of oil or gas has been attributed definitely to the Marshall formation. Hard (1938, p. 173) suggested that since the gas-producing sandstones are lateral fingers of Marshall sandstone in many areas, it is erroneous to conclude that gas is confined to sandstones of Michigan age.

It is apparent from an examination of driller's logs that in some areas drillers have erroneously referred to all sandstones at the base of the Michigan formation as Michigan "Stray" if they produce gas and as Marshall sandstone if they contain only water. In areas such as the Six Lakes field in Montcalm County where the gas producing sandstone directly overlies water-bearing sandstone (Hard, 1938, p. 159), there seems to be no question that the producing zone is Marshall in age.

Rawlins and Schellhardt (1936) and Bergquist (1938) have reviewed the discovery and production of gas from the Michigan "Stray" sandstone.

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VOL. 32, NO. 4 (APRIL, 1948), PP. 689-690, 1 FIG.

GEOLOGICAL NOTES

RAPID METHOD FOR TRANSFERRING DISTANCES FROM ONE MAP TO ANOTHER OF DIFFERENT SCALE[1]

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Evanston, Illinois

It is frequently necessary for geologists to transfer points from one map to another of different scale under conditions in which proportional dividers are not available. In such cases distances are usually converted by use of wooden scales

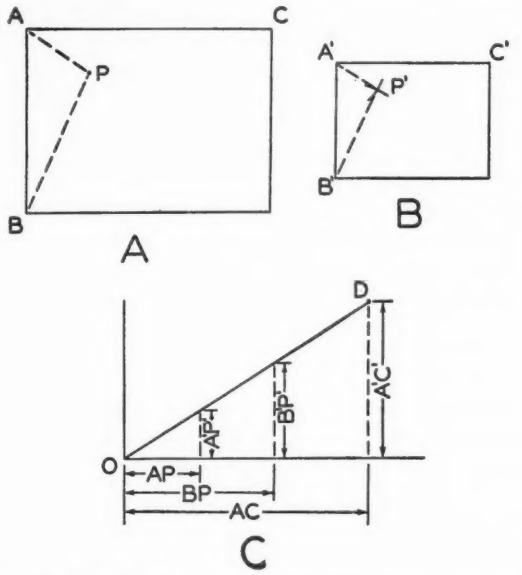

FIG. 1.—Point *P* transferred from outline map of Colorado (A) to smaller-scale outline map of Colorado (B) by use of dividers and simple straight-line diagram (C).

or of dividers and the bar scales printed on the maps. A more rapid and accurate method, requiring only ordinary dividers and an easily constructed diagram, is described in the following paragraphs.

Consider two maps of Colorado (Fig. 1, A and B) on which it is desired to transfer the point *P* from the larger map to its equivalent position *P'* on the smal-

[1] Manuscript received, February 11, 1948.

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ler map, by use of distances from the known points A and B and their equivalents A' and B'. Lay off a known distance such as AC from the first map as abscissa and the corresponding distance $A'C'$ from the second map as ordinate in a conventional coordinate diagram, as shown in Figure 1 C, and draw the straight line from the origin to the point D thus located. The line OD is the locus of all points having the ratio of abscissa to ordinate equal to the ratio of distances on the first map to corresponding distances on the second map.

To transfer the point P, measure the distance AP with dividers or drafting compass and lay off this distance horizontally to the right of the origin, then pivot the dividers about the righthand point and readjust them to the height of the line OD above this point (Fig. 1 C). The dividers (or compass) are now set to the distance $A'P'$ and may be used directly in scribing an arc about A', as shown in Figure 1 B. Similarly, the distance BP may be converted and plotted from B', the intersection of this arc with the arc from A' giving the desired location of the point P'. As many distances as desired may be converted in a similar manner by use of the same diagram.

If the diagram is constructed carefully, preferably by use of a relatively long known line, such as AC, the method can be made to yield results of the highest accuracy, for no interpolation is necessary. Care should be taken, however, to use absolutely vertical measurements on the diagram, and for this purpose it is desirable to plot the diagram on graph paper, so that the vertical direction can be determined readily.

In addition to the advantages of speed and accuracy, the method is good because it does not require knowledge of the numerical values of the map scales, or calculation therefrom. Obviously, as in most other methods, the two maps must be on the same projection.

Although this method probably has been used before, the writer has not seen it described explicitly in the literature. It is presented here in the hope that it will be helpful in the many conversions of map distances required in geologic work.

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REVIEWS AND NEW PUBLICATIONS

*Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

REVIEWS OF PETROLEUM TECHNOLOGY, BY THE INSTITUTE OF PETROLEUM

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

Reviews of Petroleum Technology. Volume 7 (covering 1941 to 1945 inclusive). Published by the Institute of Petroleum, Manson House, 26 Portland Place, London, W. 1, England. 514 pp.

As the title indicates, this book is a review of articles published between 1940 and 1946 on subjects interesting to those engaged in the technical side of oil and gas finding. There are 19 chapters, all written by outstanding authorities on various phases of oil finding and oil exploitation. Each of the authors has gone over the bibliographies carefully and selected items that would be of interest to geologists and petroleum engineers in a restricted area of present knowledge. Thus, this book becomes in effect an annotated bibliography with commentaries written by men with a background based on long-continued study of special phases of the subject. For those in our membership who wish to find out quickly what advances have been made in recent years and to do so in the shortest possible time, this book is the answer.

The first chapter was written by G. D. Hobson and is entitled Petroleum Geology. The very interesting summary presented by this eminent scholar is based on 64 references (a list of which is given at the end of the chapter). He covers such subjects as Source rocks—Organic matter in sediments—Oil formation—Bacteria in oil formation—Radioactivity—Migration mechanisms—Reservoir rocks—date of formation of enclosing rocks—Seepages—Reservoir pressure—Classification of traps—Sedimentation.

The second chapter is entitled Geophysics and was written by J. M. Bruckshaw of the Royal College of Science of London. He discusses the recent advances made in seismic methods, in gravitational and magnetic prospecting, in electrical methods of oil finding, and in radioactivity as a tool in oil finding. He suggests that the most important advances in the years covered by the review, are: (1) the use on a commercial scale of the radioactive method of well logging; (2) the use of neutron well logging; (3) greater knowledge of the velocity of elastic waves; and (4) further experiments on natural potentials. His comments on the refinements made in instruments are very helpful to the average geologist even though they may be known to the specialist on geophysics.

The chapter on Drilling reviews all articles which have been written during the years from 1940 to 1946. In addition to drilling technique such matters as cementing, plugging selectively, well surveying, coring, and well completion are discussed fully. The list of references for this chapter comprises 325 papers and articles. The chapter on Production Engineering is similarly exhaustive and reviews 355 papers and books.

The chapter on Petroleum Transportation was written by George Wilson formerly Director of Supply and Transportation of the Petroleum Administration for War. In this interesting presentation the reader will find a number of items discussed which were previously shrouded in secrecy on account of war conditions. The chapter on Refinery Process Developments was written by Gustav Egloff who needs no introduction to an American

[1] Professor of geology at the University of Wichita. Review received, February 18, 1948.

audience. Besides the refinements in the usual procedures in refining, this author also discusses fuels for jet propulsion, synthetic rubber, and lubricants.

The chapter on Analysis and Testing was prepared by C. F. McCue of the Anglo-American Oil Company. In the preparation of this review more than 1000 references to published work on the analysis and testing of petroleum products were examined. He points out that increasing use is being made of spectrographic and other physico-chemical methods of analysis. The next chapter was written by A. Winward of the Esso Development Company. It is entitled Chemistry of Petroleum and critically presents the contents of 200 separate articles. A similar review on the Physics of Petroleum constitutes the material of the next succeeding chapter. Other chapter headings are as follows: Natural Gas and Gasoline; Benzole; Alternative Fuels; Specifications for Service Fuels; Diesel Fuel and Gas Oils; Specifications for Lubricants; Asphaltic Bitumen and Road Materials; Special Products; and lastly Petroleum Literature. The chapter on Alternative Fuels is particularly timely in the United States. Fuels produced by hydrogenation and synthetic processes are discussed in the light of 133 separate articles selected from Russian, German, and Japanese sources as well as British and American sources. The alternative fuels derived from low- and medium-temperature carbonization and other types of substitute fuels are discussed on the basis of careful reviews of an additional 169 articles. Thus, a very comprehensive picture may be obtained of the present status of this most vital problem.

A very penetrating analysis of the meaning and value of recent Petroleum Literature was prepared by G. P. Kitt who reviewed 224 books and pamphlets. One of the best features of the book is the Index which lists all titles both under author and also under subject.

OIL AND GAS FIELD DEVELOPMENT IN UNITED STATES 1946, BY NATIONAL OIL SCOUTS AND LANDMEN'S ASSOCIATION

REVIEW BY C. G. STRACHAN[1]
Tulsa, Oklahoma

Oil and Gas Field Development in the United States, Year Book 1947 (Review of 1946). Edited by Hugh J. Roberts and E. J. Raisch. 943 pp., maps, tables, charts. 7.5×10.5 inches. Published by National Oil Scouts and Landmen's Association, Austin, Texas. Price, $7.50, cloth-bound.

As an opening comment in this review, the reviewer is justified in expressing again the idea advanced last year; it is that for one man to presume to criticize the massive collection by many men of the data in this book is a form of impertinence. As in the 1945 edition it carries production by fields, past and present, discoveries and associated data for the year, the location and amount of leasing and geophysical and geological work, regional geological maps, pool maps, and stratigraphic sections.

There are 32 sections in which are discussed as many states or group of states as units, besides other sections of a more general nature. The introduction is short, but it points out the highlights of the petroleum situation for 1946; they are, or at least at the time were, well worth knowing. Consumption of petroleum, in spite of it being the first full post-war year, was down only 1 per cent, to an average of about 5,305,000 barrels daily. Crude production, which was expected to be curtailed, gained 20 million barrels to total 1,731,889,000 barrels for the year. Despite this increase, the country imported 134,698,000 barrels of crude oil and petroleum products. Wildcatting was at a peak with such tests numbering 4830 compared with the previous peak of 4510 in 1945. The drilling resulted in 411 new oil and gas

[1] Gulf Oil Corporation. Review received, February 27, 1948.

fields and the discovery of 276 new producing formations in previously found pools. In the appendix discussing the country's reserves at the end of 1946 the figures arrived at by the American Gas Association and the American Petroleum Institute are presented. Of chief interest is the figure of 24,227,447,000 barrels of proved reserves of liquid hydrocarbons. Proved gas reserves are given as 160,575,901 million cubic feet.

It is regrettable that the assembling of these data cannot be done so as to get the book to readers much earlier. As a member of the A.A.P.G., this reviewer would be amiss in not pointing out that much of the material which is of interest to geologists appeared in the June, 1947, *Bulletin*. It should be noted, however, that the book under review carries a section on the Rocky Mountains, which the *Bulletin* does not. On the other hand the *Bulletin* discusses Canada; because of the increasing activity by American major oil companies and the discovery of new pools in Alberta, the scouts and landmen may feel constrained to include this region in a future publication.

RECENT PUBLICATIONS

ALBERTA

*"The Cretaceous—Tertiary Boundary in the Foothills of Central Alberta," by R. L. Rutherford. *Trans. Royal Soc. Canada*, 3d. Ser., Sec. 4, Vol. 41 (Ottawa, 1947), pp. 47–59.

ARGENTINA

*"Los depósitos plantiferos de Piedra del Aguila (Neuquen) y sus relaciones" (Plant Beds of Piedra de Aguila and Their Relationships), by Roberto Ferello. *Y.P.F. Bol. Inf. Petrol.*, Vol. 24, No. 278 (Buenos Aires, October, 1947), pp. 248–61; 13 figs. (fossils), 3 photographs, areal map, and transverse geological section.

CHINA

*"Remarques sur les flexures continentales de Chine" (Continental Folding in China), by P. Teilhard de Chardin. *Bull. Soc. Geol. France*, 5th Ser., Vol. 16, Nos. 7–8–9 (Paris, 1946; published, October, 1947), pp. 497–302; 2 figs.

EAST INDIES

**Geological Explorations in the Island of Celebes*. By commission of the Netherlands East Indies Geological Survey in 1929, with the collaboration of W. H. Hetzel and H. E. G. Straeter, under the leadership of H. A. Brouwer, professor of geology at the University of Amsterdam. Geological Summary and Petrology, by H. A. Brouwer, W. P. de Roever, and C. G. Egeler. 346 pp. 7×9.5 inches. 24 pls. (mostly photomicrographs of metamorphosed and igneous rocks; 25 text figs., 2 folded sketch maps.

" . . . in Central Celebes the surface geology shows . . . three main zones . . .

1. An eastern zone, which is characterized by the abundance of basic and ultra-basic igneous rocks, Mesozoic and possibly older limestones and siliceous rocks, which partly are rich in radiolaria.

2. A central zone of epi- to meso-metamorphic muscovite-rich crystalline schists. In the main the degree of regional metamorphism decreases from west to east.

3. A western zone, which is characterized by the abundance of granodioritic and various volcanic rocks, biotite-rich crystalline schists and sediments, which generally have been deposited in water shallower than that of zone 1."

North Holland Publishing Company (N. V. Noord-Hollandsche Uitgevers Mij.), Amsterdam, Holland (1947). Clothbound. Price, f27.50.

*"Two Problems of Marine Geology: Atolls and Canyons," by Ph. H. Kuenen. *Verh. Koninklijke Nederlandsche Akad. van Wetenschappen, afd. Natuurkunde*, Tweedie Sectie, Deel 43, No. 3 (1947, pp. 1–69; 4 pls., 14 text figs. I. "The Borings on Maratoea Atoll and the Coral Reef Theory of Glacially Controlled Subsidence," pp. 5–36. II. "Submarine Canyons and Their Formation," pp. 37–69. Published by N. V. Noord-Hollandsche Uitgevers Maatschappij, Amsterdam, Holland. Paper. 7.125×10.25 inches. In English.

FLORIDA

*"Exploration for Oil and Gas in Florida," by Herman Gunter. *Florida Geol. Survey Inf. Cir. 1* (Tallahassee, January 1, 1948). 68 mimeog. pp. 8.5×11 inches. 2 figs., 2 tables.

**Southeastern Geological Society, Fifth Field Trip, West-Central Florida, December 5-6, 1947*. 71 mimeog. pp. 8.5×11 inches. Folded map in pocket. Copies may be purchased from Secretary, Southeastern Geological Society, Box 841, Tallahassee, Florida, Price, $3.00.

FRANCE

*"Sur la stratigraphie du Flysch au sud de Pau, Basses-Pyrénées" (Stratigraphy of Flysche South of Pau, Basses-Pyrénées), by Y. Gubler. *Bull. Geol. Soc. France*, 5th ser., Vol. 16, Nos. 7–8–9 (Paris, 1946, published, October, 1947), pp. 401–22; 1 stratigraphic chart.

*"Nouvelles observations stratigraphiques dans l' Eocene au sud de Pau, Basses-Pyrénées" (New Stratigraphic Notes on the Eocene South of Pau), by Y. Gubler and R. Pomeyrol. *Ibid.*, pp. 423–44; 2 figs., 2 folded stratigraphic and microfaunal charts.

GENERAL

*"Studies for Students." "A Preface to the Classification of the Sedimentary Rocks," by F. J. Pettijohn. *Jour. Geology*, Vol. 56, No. 2 (Chicago, March, 1948), pp. 112–17.

*———, "A Classification of Sedimentary Rocks," by Robert R. Shrock. *Ibid.*, pp. 118–29; 1 table.

*———, "The Megascopic Study and Field Classification of Sedimentary Rocks," by Paul D. Krynine. *Ibid.*, pp. 130–65; 15 figs., 4 tables.

*"Correlation of the Mississippian Formations of North America," by the Mississippian Subcommittee, J. Marvin Weller (Chairman). *Bull. Geol. Soc. America*, Vol. 59, No. 2 (New York, February, 1948), pp. 91–188; 330 refs., 7 figs., 1 pl., 1 folded correlation chart.

Report of the American Petroleum Institute's Committee on Petroleum Reserves, by F. H. Lahee (Chairman). 9 mim. pp. Printed copies available from Dept. Information, American Petroleum Institute, 50 West 50th Street, New York 20, N. Y.

Report of the Committee on Natural Gas Reserves of the American Gas Association, by N. C. McGowan (Chairman). 7 mim. pp. Printed copies available from Dept. Information, American Petroleum Institute, 50 West 50th Street, New York 20, N. Y.

*"Bibliographic Index of Permian Invertebrates," by Carl C. Branson. *Geol. Soc. America Mem. 26* (New York, February 26, 1948). 1049 pp.

*"Flying Magnetometer, Tool of Aerial Exploration," by Homer Jensen. *World Petroleum*, Vol. 19, No. 3 (New York, March, 1948), pp. 84–87; 4 photographs.

**Geophysical Directory* (East of the Rocky Mountains). 120 pp. 1948 edition. A comprehensive directory for the entire geophysical industry, listing geophysical contractors, shot-hole and core-drill contractors, oil companies using geophysics, personnel, *et cetera*. The Geophysical Directory, Box 6646, Houston 5, Texas. Price, $3.00.

Photogrammetric Engineering, Vol. 13, No. 4 (December, 1947). Issue devoted to Photogrammetry in Geology symposium, compiled by H. T. U. Smith, with papers by Mark Baldwin, Howard M. Smith, Howard W. Whitlock; Robert S. Dietz; Y. O. Fortier; A. H. Lang: Raymond C. Moore: William C. Putnam; John Lyon Rich: G. W. Rooney; W. S. Levings; F. T. Thwaites; Sherman A. Wengerd; John D. Strobell, Jr.; pp. 531–628, illus. Total pp. in complete issue, 531–720. Published quarterly by the American Society of Photogrammetry, Box 18, Benjamin Franklin Station, Washington, D. C. Price per copy, $1.50.

INDIA

*"Microfossils and the Salt Range Thrust," by B. Sahni. *Proc. Natl. Acad. Sci. India*, Vol. 16, Pts. 2–4 (Lucknow, 1946). 50 pp., 11 pls.

*"Second Symposium on the Age of the Saline Series in the Salt Range of the Punjab." Held under the joint auspices of the National Academy of Sciences and the Indian Academy of Sciences at Udaipur, December 27 and 28, 1945. *Proc. Natl. Acad. Sci. India*, Vol. 16, Pts. 2–4 (Lucknow, 1946), pp. 229–47.

*"Paleontology and the Measurement of Geological Time," by B. Sahni. *Current Science*, 16 (July, 1947), pp. 203–06. Comments and suggestions for a plan of research by the committee on the measurement of geological time in India.

ITALY

*"Per la geologia delle argille ofiolitifere appenninche. Nota III. Foraminiferi dell'argilla scagliosa di Castelvecchio (Modena)" (Geology of Ophiolitic Clay of the Appennines. Note III. Foraminifera of Micaceous Clay of Castelvecchio, Modena), by E. Montanaro Gallitelli. *Atti della Soc. Toscona di Sci. Naturila*, Mem., Vol. 45 (Pisa, 1947). 24 pp.; 3 figs. Italian.

KANSAS

*"Geology and Ground-Water Resources of Kiowa County, Kansas," by Bruce F. Latta. *Kansas Geol. Survey Bull. 65* (Lawrence, February, 1948). 151 pp., 11 pls., 10 figs., 9 tables.

NORTH CAROLINA

*"North Carolina Coastal Plain Floor" (abstract), by Willard Berry. *Bull. Geol. Soc. America*, Vol. 59, No. 2 (New York, February, 1948), pp. 87–89; 1 pl., 1 fig.

ROMANIA

*"Structura geologica a regiunii dentre Mizil si Targoviste, cu privire speciala-asupra carbunilor din Dacian" (Geological Structure in the Region between Targoviste and Mizil) by N. Oncescu. *Inst. Geol. Romaniei Geol. Econ.*, Ser. A, Nr. 3 (Bucuresti, 1947). 63 pp., 8 text figs., 1 folded map in colors. In Romanian.

SPAIN

"Revisión de algunos datos paleontológicos de flysch cretáceo y numulítico de Guipúzcoa" (Revision of Paleontological Data of the Cretaceous and Nummulitic Flysch of Guipuzcoa), by Joaquim Gomez de Llarena. *Inst. Geol. Min. España*, Notas y Comunicaciones, Num. 15 (Ríos Rosas, 9, Madrid, 1946), pp. 109-66; 5 figs., 8 pls. Spanish.

"Datos para el estudio de la hoja geologica de Cabrejas del Pinar, Soria" (Data for the Study of the Geology of the Cabrejas del Pinar, Soria), by Jose Cantos Figuerola Saiz de Carlos. *Ibid.*, pp. 167–74; 1 fig., 2 folded, colored pls. (structure sections, e.g., anticlinal de la Cuenca, and geological map).

TEXAS

*"*Geology and Ground Water Resources of Comal County, Texas*, by William O. George *et al.* Texas Board of Water Engineers, Austin (February, 1947). 142 pp. Approx. 8.5×11 inches. Multigraphed. 5 pls., 7 figs. Prepared in cooperation with U. S. Geological Survey.

UTAH

*"Oil Prospects in Utah," by Glen M. Ruby. *Oil and Gas Jour.*, Vol. 46, No. 41 (Tulsa, February 12, 1948), pp. 87–96, 104; 3 maps.

WYOMING

"Geologic and Structure Contour Map of the Basin-Greybull Area, Big Horn County, Wyoming," by William G. Pierce. *U. S. Geol. Survey. Prelim. Map 77*, Oil and Gas Inves. Ser. (February, 1948). Sheet, 35×51 inches. Scale, 1 inch equals 4000 feet. May be purchased from Director, U. S. Geological Survey, Washington 25, D. C. Price $0.60.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 4 (APRIL, 1948), PP. 697-705

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

NEWS OF THE PROFESSION

FIELD CONFERENCE IN WIND RIVER BASIN, WYOMING, AUGUST 11–14, 1948

The Wyoming Geological Association's third annual field conference will be held in the Wind River Basin, Wyoming, from August 11 to 14. Registration will start at 4:00 P.M. in the Noble Hotel at Lander, the conference headquarters. Field trips on August 12, 13, and 14 out of Lander are planned, which, together with lectures scheduled for evening meetings, will permit examination and discussion of the most important features of the geology of the Wind River Basin, including structure, stratigraphy, and major oil fields. The conference will end in Casper on the night of August 14.

A guide book is being prepared which will contain road logs of all the principal roads of the Wind River Basin and original articles on structure, stratigraphy, individual oil and gas fields, and other features of interest. It is planned to illustrate the guide book with numerous maps, sections, and photographs. Authors contributing to the guide book include geologists of the Wyoming Geological Association, the University of Wyoming, the United States Geological Survey, and the University of Missouri.

The general direction and organization of the conference is under the chairmanship of PHILIP W. REINHART, of the Shell Oil Company, Incorporated. The guide book is being prepared by an editorial board under the supervision of JED B. MAEBIUS of the Gulf Oil Corporation. Registration, accommodations, and general arrangements are being taken care of by a group headed by F. HOWARD BRADY of Chemical and Geological Laboratories, Incorporated.

The Lander Chamber of Commerce and the management of the Noble Hotel at Lander are taking an active part in arranging for accommodations, meals, and entertainment.

All interested geologists are invited to take part in the conference. As it will be necessary to limit registration to approximately 175 participants, those wishing to attend are asked to communicate immediately with F. HOWARD BRADY, Box 279, Casper, Wyoming. Automobile transportation from Casper to Lander on August 11 will be provided for out-of-state visitors who desire it. Likewise, automobile transportation for all participants will be available for the trips out of Lander and back to Casper.

P. W. REINHART, *Chairman*
Field Trip Committee

DISTINGUISHED LECTURE TOUR

The itinerary of CLARK GOODMAN, associate professor at the Massachusetts Institute of Technology, follows. His subject was "Radioactivity and Petroleum Geology."

March 8 Tulsa Geological Society, at University of Tulsa
9 Oklahoma City Geological Society
11 North Texas Geological Society, Wichita Falls
12 Texas Technological College, Lubbock
15 Corpus Christi Geological Society
16 Fort Worth Geological Society and Geology and Physics Departments of Texas Christian University
17 Dallas Geological Society, at Southern Methodist University
18 Shreveport Geological Society
19 Southeastern Geological Society, Tallahassee

The American Geophysical Union holds its 29th annual meeting in Washington, D. C., April 21–23.

NELSON HORATIO DARTON, honorary member of the Association, for many years a geologist of the United States Geological Survey, died at Chevy Chase, Maryland, February 28, at the age of 82 years.

W. C. MACQUOWN, JR., recently resigned as assistant professor of geology at the University of Kentucky and has opened a district geologic office for the Cooperative Refinery Association in Oklahoma City, Oklahoma. The new address is 716 Braniff Building.

HELEN K. FOSTER, recently at Wellesley College, is with the Military Section of the United States Geological Survey, and is to be stationed in Japan.

M. KING HUBBERT, of the Shell Oil Company, Inc., spoke on "The Motion of Ground Water," before the Houston Geological Society, March 8.

GEOLOGISTS NEEDED FOR ADTIC SERVICE

Geologists and other professionally trained personnel with experience in non-temperate regions are desired for civilian appointment to the staff of the Arctic, Desert and Tropic Information Center of the U. S. Army Air forces. The ADTIC is being re-established at the Air University, Maxwell Field, Alabama, in accordance with a recent directive from Air Force Headquarters. Civil Service ratings will range from P–2 to P–6 ($3400 to $8000). Inquiries should be addressed to CHARLES M. THOMAS, Chief, Documentary Research Division, Air University Library, Maxwell Field, Alabama. (The wartime staff of ADTIC included eleven geologists, five of them members of the A.A.P.G.)

JAMES C. MONK, of the Sun Oil Company, has been transferred from Jackson, Mississippi, to the home office in Philadelphia, Pennsylvania.

ROBERT L. ALKIRE, assistant petroleum research engineer, Engineering Experiment Station, West Virginia University, Morgantown, joined the staff of the Ohio Geological Survey as oil and gas geologist, effective March 1, it has been announced by JOHN H. MELVIN, Ohio State geologist, Columbus, Ohio.

R. C. STEPHENSON, of the Pennsylvania Geological Survey, discussed "Uranium and Vanadium Deposits of the Colorado Plateau Area" at a meeting of the Pittsburgh Geological Society held at the William Penn Hotel on February 10.

JOSEPH M. GORMAN, geologist with the Creole Petroleum Corporation, Caracas, Venezuela, returned to the States on long vacation in mid-April. From April 30 to June 10 he may be reached at 59 Burke Street, Plains, Wilkes-Barre, Pennsylvania, c/o Mrs. Richard Gorman.

PAGE T. JENKINS, formerly in the employ of the Carter Oil Company, is district geologist for the Seaboard Oil Company of Delaware at Casper, Wyoming.

BERNARD ROMAINE HASBROUCK died, November 10, 1947, in Panama, where he was in the employ of the Sinclair Panama Oil Corporation.

J. C. FINLEY, chief geologist for the Midstates Oil Company, Tulsa, has resigned to become manager of exploration for the Kerr-McGee Oil Industries, Inc., Oklahoma City.

JOHN L. LESTER has resigned from the Shell Oil Company, Inc., and has opened a consulting office in Centralia, Illinois. His Postoffice Box is 249.

MAX B. PAYNE has left the Union Oil Company of California and is district geologist for the Signal Oil and Gas Company, Bakersfield, California.

J. R. TICHY has resigned from the Shell Oil Company, Inc., to accept a position as geologist with the Sun Oil Company at Denver, Colorado.

JOHN S. BARWICK, of Wichita, Kansas, is in the employ of the Corporacion de Fomento de la Produccion, Punta Arenas, Chile.

ROBERT F. IMBT has moved his office as consulting petroleum geologist from Midland to 2005 Fort Worth National Bank Building, Fort Worth, Texas.

BRITAIN W. WALTON and THOMAS S. NAPIER have organized Seismic Analysis, Inc., Room 208 at 115½ Jefferson Boulevard, Dallas, Texas.

WILBERT S. LARSON, JR., recently with The Texas Company at Shawnee, Oklahoma, is geologist with the Chemical and Geological Laboratories, Inc., Casper, Wyoming.

CHARLES BOYD MORGAN has left the National Associated Petroleum Company to accept the position of geologist with the Seaboard Oil Company of Delaware at Abilene, Texas.

A. N. MCDOWELL has left the Creole Petroleum Corporation, Caracas, Venezuela. He may be addressed at 2106 Laurel Street, Texarkana, Arkansas.

ELDON HOUSE is employed by the Husky Refining Company, Cody, Wyoming.

M. KING HUBBERT, of the production and research division of the Shell Oil Company at Houston, Texas, talked about "The Mechanical Basis for Faulting and Related Geologic Structures," at the meeting of the Shreveport Geological Society and the Ark-La-Tex Geophysical Society, at Shreveport, March 9.

C. W. SANDERS, chief geologist for Danciger Oil and Refining Company during the past 4½ years, is resigning on May 1 in order to engage in consulting work. His office will be at 2413 Colonial Parkway, Fort Worth 4, Texas.

ROLLIN THOMAS CHAMBERLIN, professor emeritus of geology at the University of Chicago, and editor emeritus of the *Journal of Geology*, died at Chicago, at the age of 66 years.

E. R. BRANSON has resigned his position as district geologist for the Carter Oil Company at Mount Pleasant, Michigan, to become vice-president in charge of exploration for the Turner Oil Corporation.

RODERICK G. MURCHISON is on leave of absence from the Socony-Vacuum Oil Company of Colombia in order to enroll for graduate studies at the University of North Carolina. His address is Rocky Mount, North Carolina.

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By

J. V. HOWELL AND A. I. LEVORSEN
Tulsa, Oklahoma, and Stanford University, California

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- A. Publications and non-commercial publishing agencies, regional, national, and continental
- B. Bibliographies, general
- C. Dictionaries, glossaries, encyclopedias, statistics, handbooks
- D. Miscellaneous books and publications of general geological interest
- E. Commercial map publishers
- F. Regional and national geologic and physiographic maps
- G. State and Province geological maps
- H. Trade journals: oil, gas, mineral industry
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- B. Central American countries
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BOX 979, TULSA 1, OKLAHOMA, U.S.A.

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Vice-President - - - - - - Don W. Payne
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Cities Service Oil Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

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Meets the first Monday of every month, October-May, inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Secretary-Treasurer - - - - - Carl F. Grubb
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Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Treasurer - - - - - - - - R. W. Edmund
Globe Oil and Refining Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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Shawnee

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Ohio Oil Company, Thompson Building
Editor - - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Student Union or Tyrrell Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

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Treasurer - - - - - - - - C. H. Feldmiller
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Meetings held each month, except during the summer. All meetings and other activities by special announcement.

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Meetings: 2d Thursday of each month, 7:00 P.M., Wooten Hotel.

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Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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Executive Committee - - - - Barney Fisher
Comanche Corporation
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Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Box 1410
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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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TEXAS

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Secretary-Treasurer - - - Joseph W. McDonald
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Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Magnolia Petroleum Company, Box 1988

Vice-President - - - - - - - Robert J. Gutru
Cities Service Oil Company, Box 350

Secretary-Treasurer - - - - Fred S. Alexander
Standard Oil Company at Texas, Box 2087

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Vice-President - - - - - - - Sam C. Giesey
Union Oil Company of California

Secretary - - - - - - - - Clyde W. Turner
Gulf Oil Corporation, Box 1150

Treasurer - - - - - - - - Jane M. Johnson
Permian Basin Sample Laboratory, Box 1653

Meetings will be announced.

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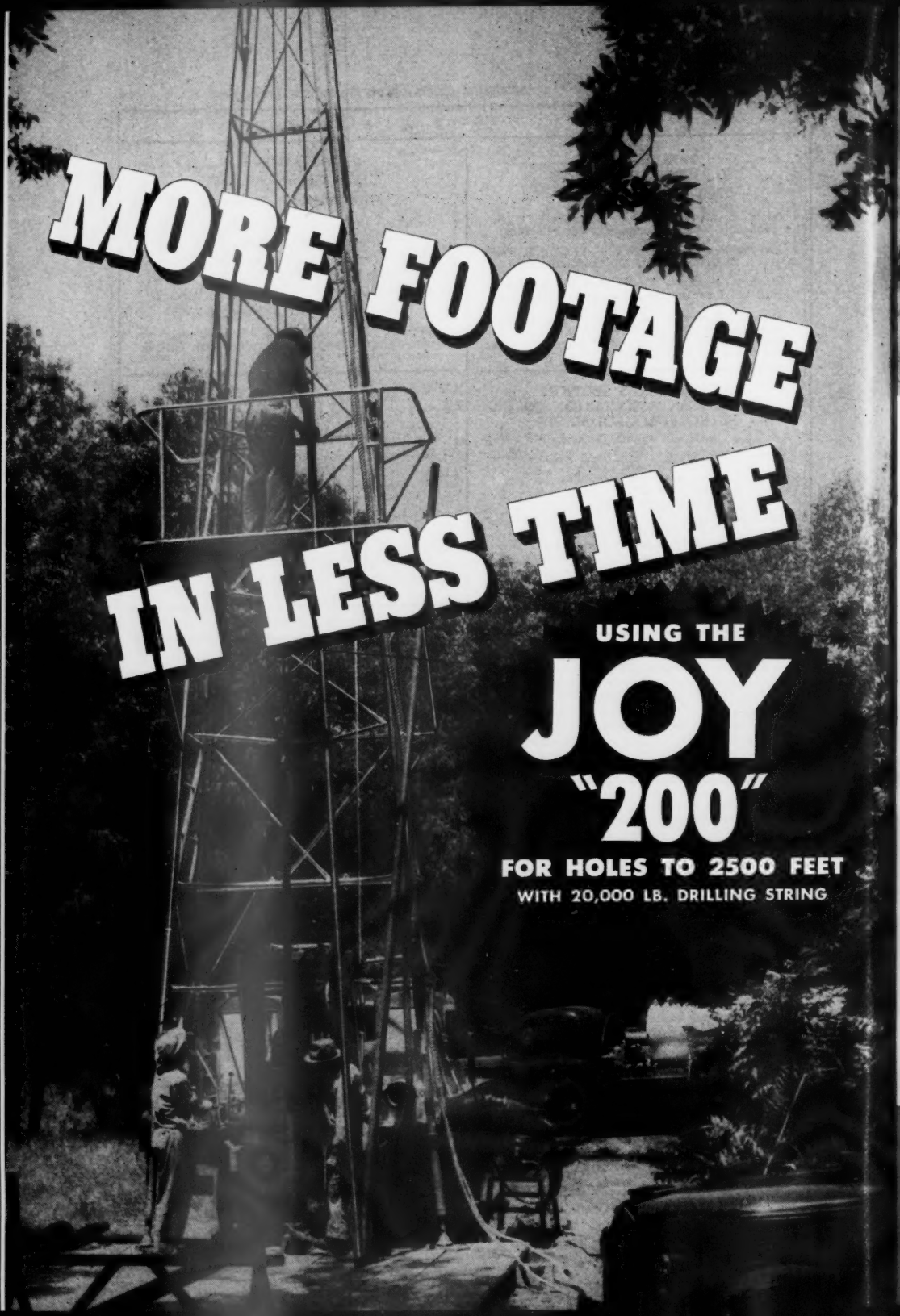
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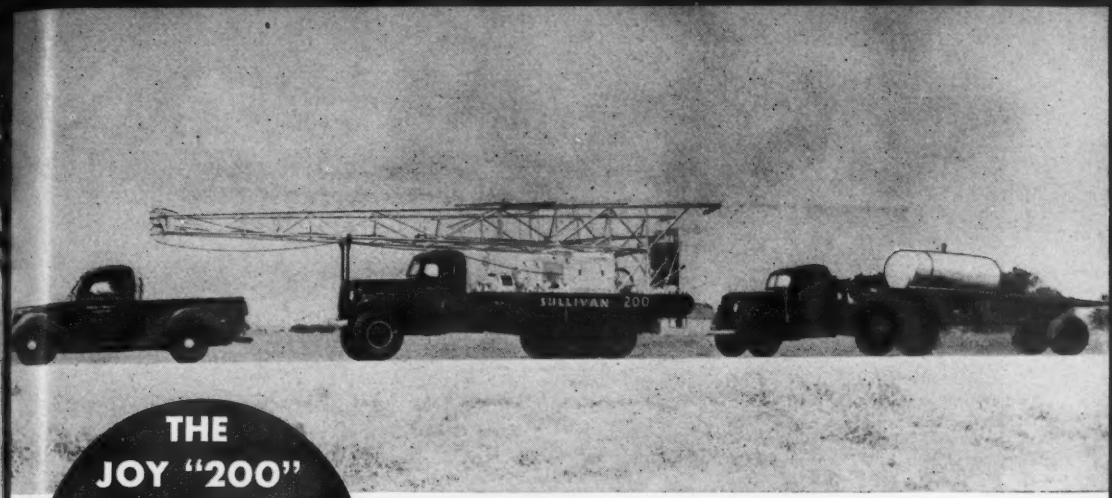

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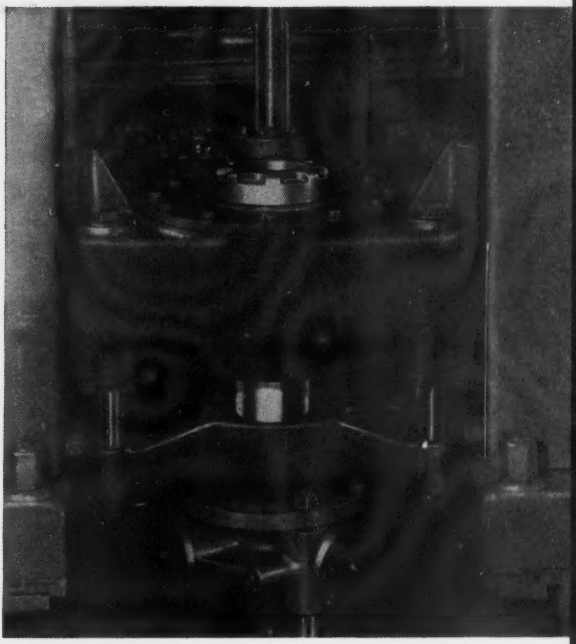

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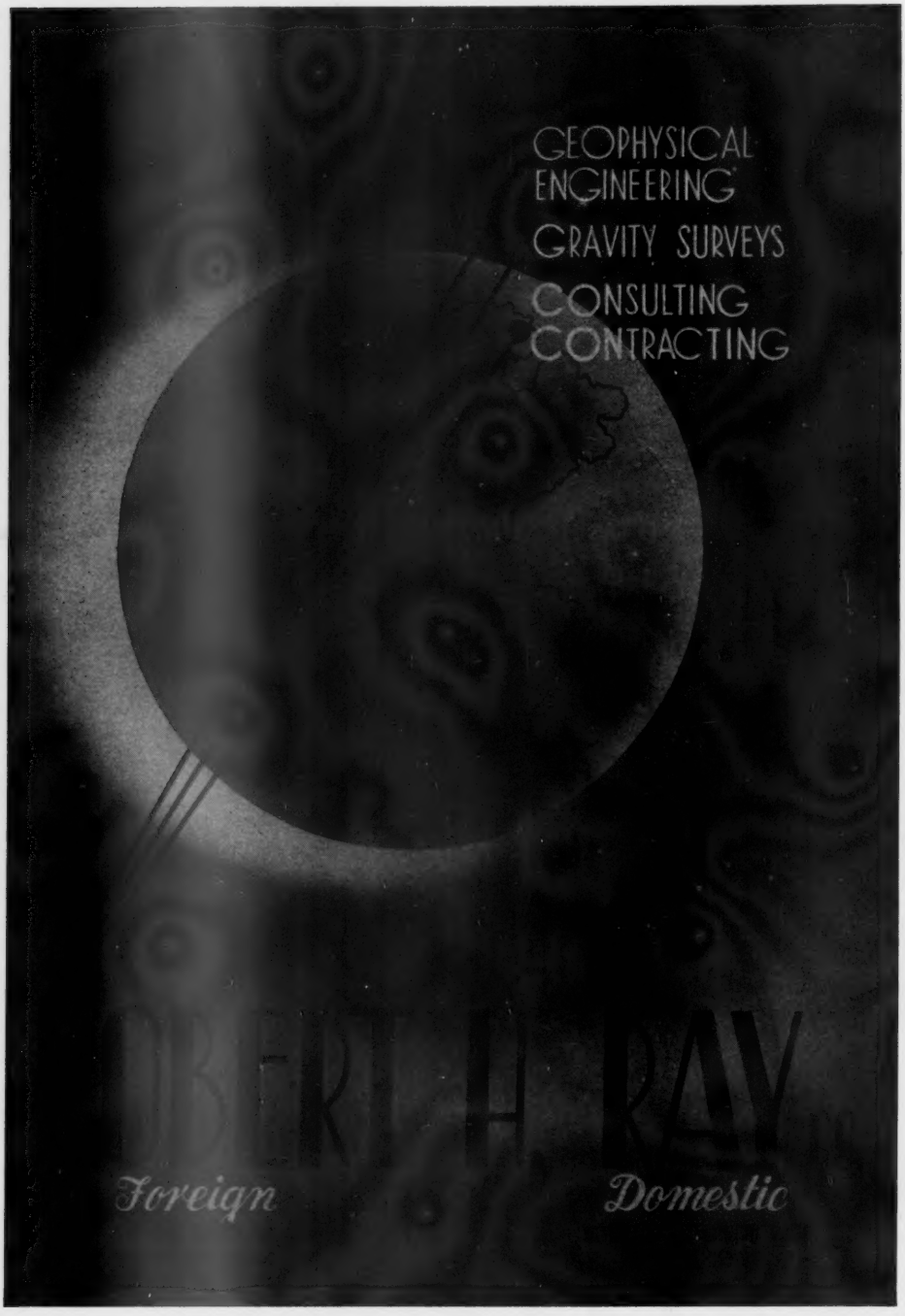
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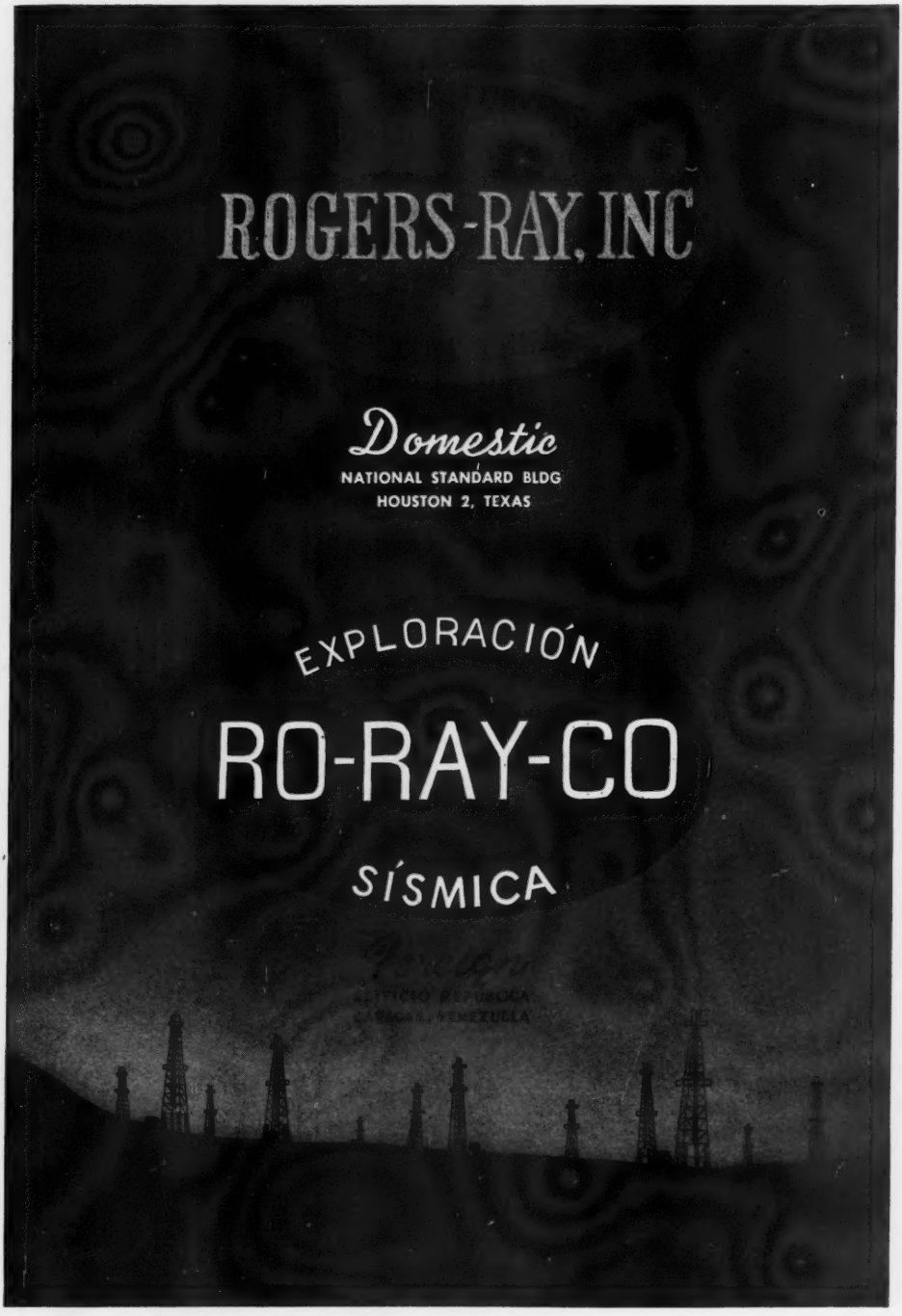
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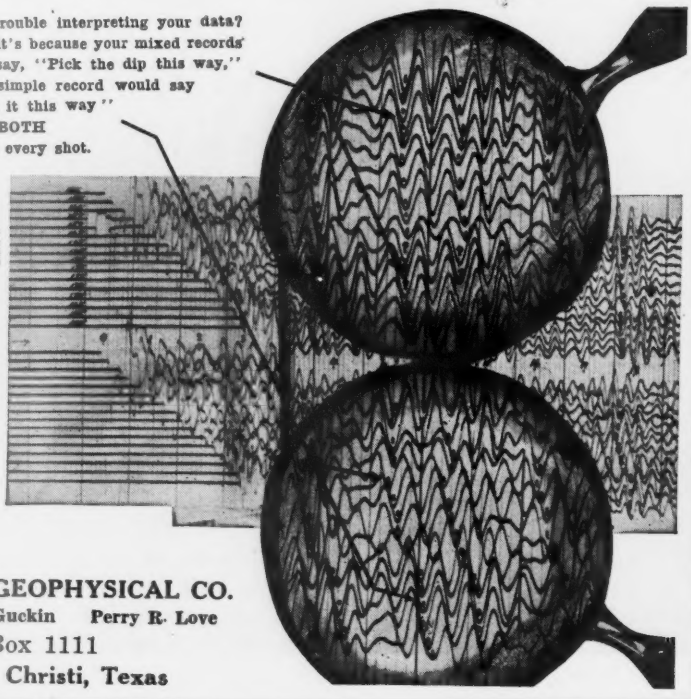

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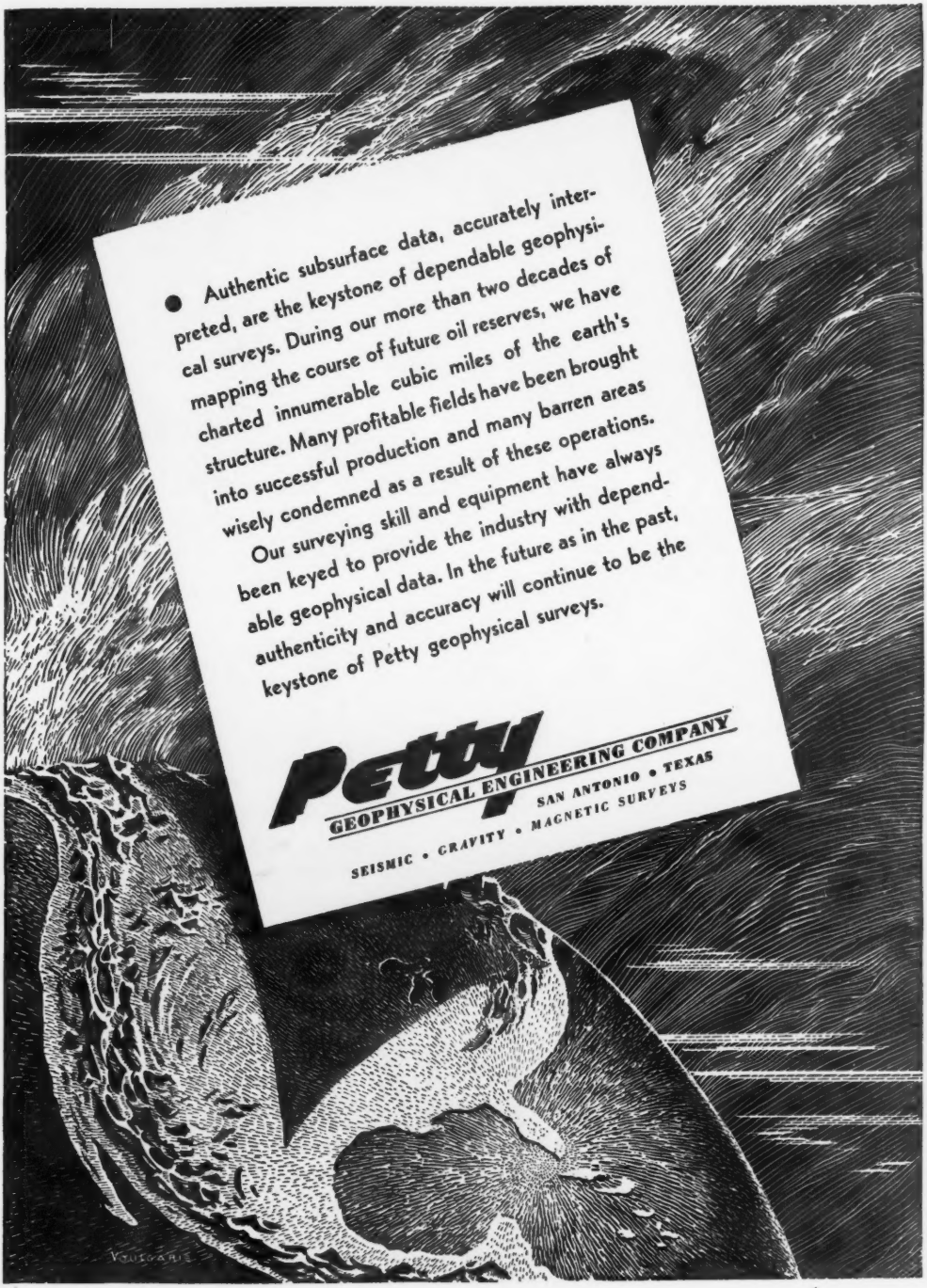
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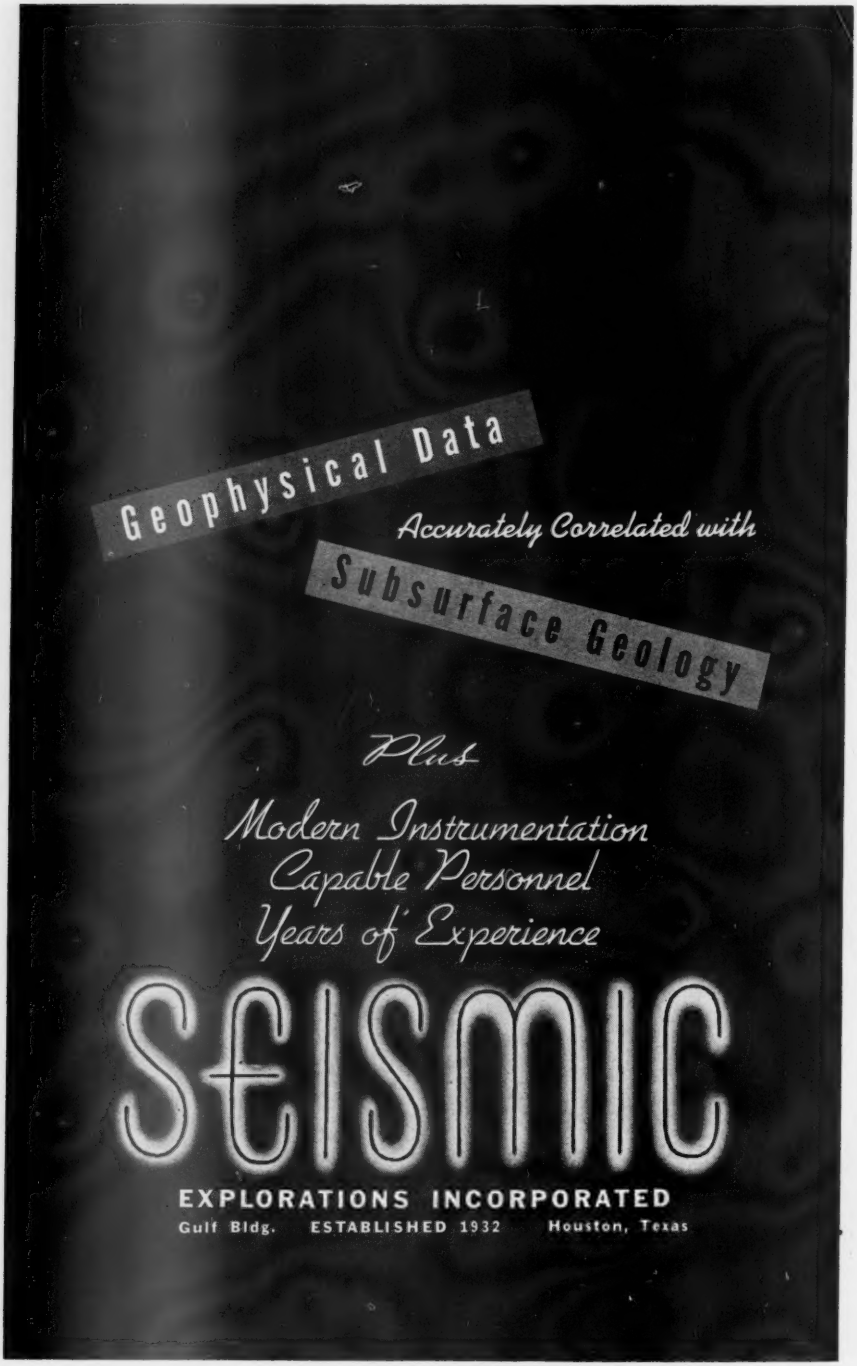
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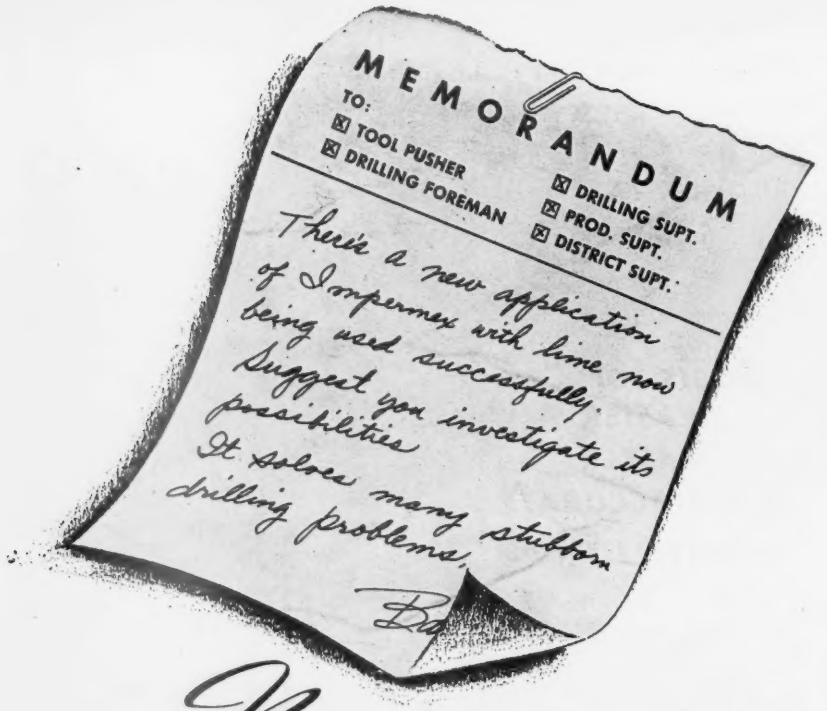
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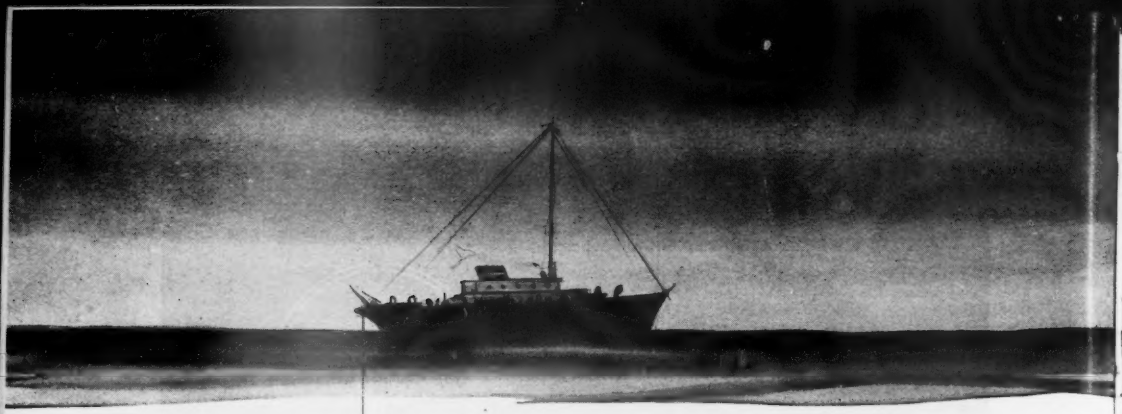

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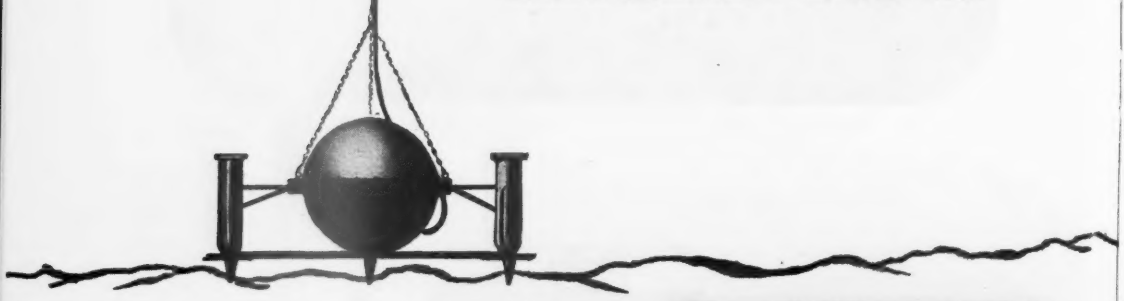

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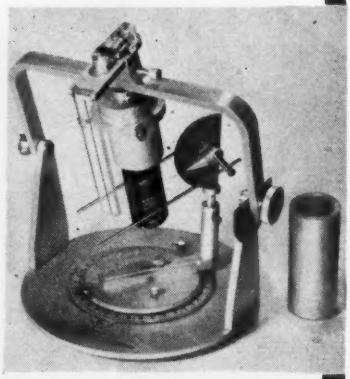

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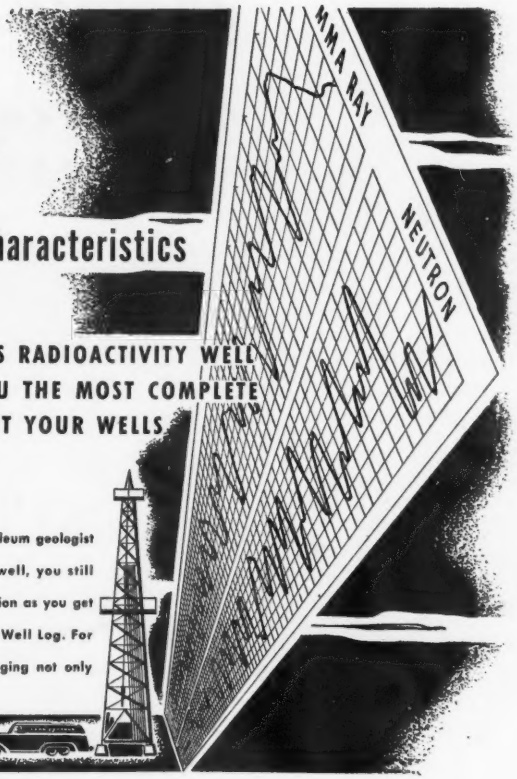

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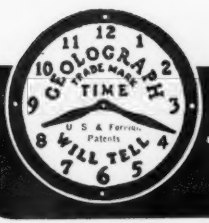

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OF THE PUBLICATIONS OF
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

1917-1945

***By* DAISY WINIFRED HEATH**

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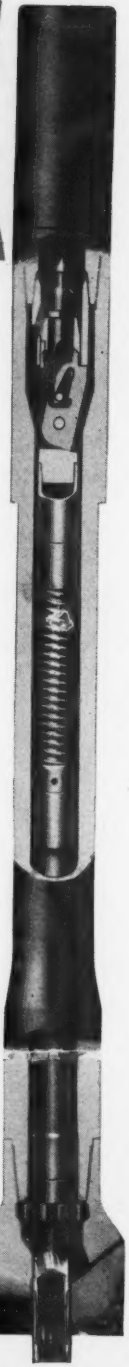

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FOR INTERMITTENT OR CONTINUOUS CORING

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Schematic view of oil sands surrounding the zone of production showing how the surface tension of water particles locks them in the minute crevices thereby blocking off the flow of crude oil.

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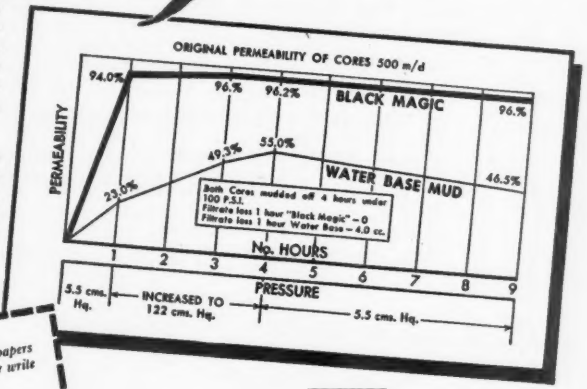

CURVES

Synthetic cores of 500 m/d mudded off—one with Black Magic, one with a starch treated clay mud. Cores were deplastered with simulated crude (80% white oil, 20% Kerosene) and permeability measured over a nine hour period. Note approximate full recovery of original permeability in one hour by core mudded off with Black Magic.

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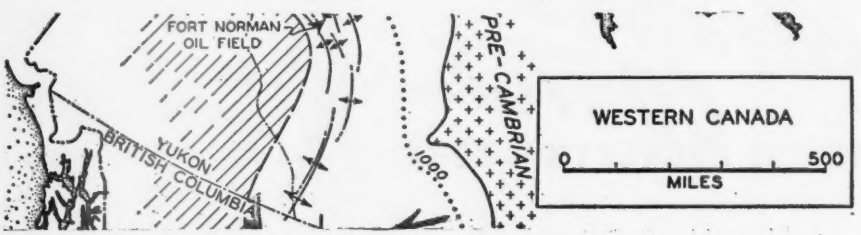

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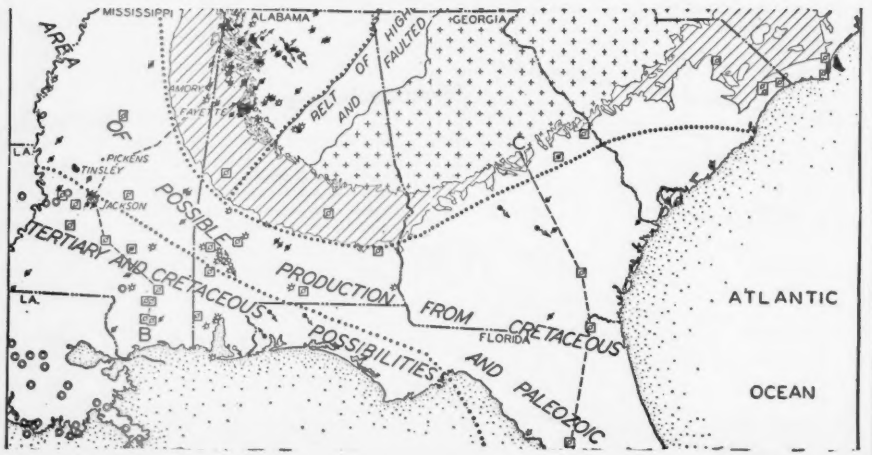

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By ROBERT M. KLEINPELL

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